Studienarbeit January 15.2020

Instrumentation and measurement platform aeronautics inspired, based on LabView

from

Nadège Prévost

The project contains
Pages: 61
Figures: 46
Charts: 11

Institut für Flugführung
Technische Universität Braunschweig ·
Tutor & advisor: Dr. Astrid Lampert

MCIA center Innovation Electronics
Universitat Politècnica de Catalunya
Assistant professor: Miguel Delgado Prieto

January 2020

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola Superior d'Enginyeries Industrial,
Aeroespacial i Audiovisual de Terrassa

Student Thesis

for

Nadège Prévost

<u>Instrumentation and measurement platform, aeronautics inspired, based on LabView</u>

Background

Instrumentation and measurement systems are constantly gaining in importance. Especially in the aeronautic sector they are essential in order to assure a secure process in which not every step has to be controlled manually. The data is converted from analogue to digital and then processed and visualized on monitors or panels.
Currently the MCIA center Innovation Electronics of the Universitat Politècnica de Catalunya started a new series of practical sessions for an aeronautic subject related to instrumentation. Sensors of all type are being connected to LabView through an acquisition system of National Instruments in order to analyze and visualize the data on a panel.
The aim is to provide a system that allows gaining rapidly insight in the functionality of LabView and acquiring knowledge about the processing of data within a professional acquisition and instrumentation environment.
Choosing different sensors (with different output, digital, analogue, modular etc.) and connecting them to LabView gives the possibility to later on connect every other sensor of the same outcome type to the environment. With little changes every sensor will be able to be visualized on the panel.

Objective of the work

The main goal of the project is the design and development of an instrumentation and measurement platform to visualize data of a set of sensors through an acquisition system and a virtual panel.
The following tasks have to be accomplished:

- Familiarization with the LabView environment
- Selection and integration of different sensors in LabView
- Implementation of digital processing procedures for sensors adaption
- Design of a panel for displaying measurement parameters
- System validation
- Documentation of the thesis

Recommended Literature:

[1] Armando Péreza, Gisela Monterob, Rogelio Ramos Irigoyenb, Conrado Garciab, Marcos Coronadob, Jose Rodrigueza: Development and implementation of virtual instrumentation based on LabView applied to compression ignition engines operated with diesel-biodiesel blends, Method Article, 2019

[2] Amit Kumar Rohit, Amit Tomar, Anurag Kumar, Saroj Rangnekar: Virtual lab based real-time data acquisition, measurement and monitoring platform for solar photovoltaic module, Resource-Efficient Technologies Journal, 2017

[3] Kunliang Xu: The Design Concept of a Virtual Experiment Teaching Platform for Digital Logic Based on LabVIEW, International Journal of Hybrid Information Technology, 2015

[4] Nan Su, XiaoWei Tu, QingHua Yang, XuHui Li, Yan Tong: Design of Data Communication and Monitoring System Based on Aviation ARINC825 Bus, International Conference on Communication Software and Networks, 2019

[5] José Roberto Quezada Peña, Jefferson Oliveira, Manuel Leonel da Costa Neto, Luis Henrique Neves Rodrigues: ACTIVE METHODOLOGIES IN EDUCATION OF ELECTRONIC INSTRUMENTATION USING VIRTUAL INSTRUMENTATION PLATFORM BASED ON LABVIEW AND ELVIS II, Global Engineering Education Conference (EDUCON), 2018

Duration:

The duration of the student thesis is **3 months** according to the current valid version of examination regulation (PO). Upon accepting the task description, the student confirms that he/she is familiar with the current valid PO that applies for his/her degree programme.

Further arrangements:

1. The thesis shall be written in coordination with the advisor. The thesis or parts of it must not be published or passed on to third parties without consulting the Institute.
2. Compliance with the „Richtlinien und Hinweise für die Anfertigung von Studien-, Diplom-, Bachelor- und Masterarbeiten" (Recommended Practices and Guidelines for Student, Diploma, Bachelor and Master Theses) of the Institute for Flight Guidance of the TU Braunschweig shall be assured.
3. As far as use of equipment and facilities at the Institute of Flight Guidance is necessary, their use is limited to normal working hours of the Institute; beyond that only after consulting the advisor. In any case, at least one other person must be in visual or hearing range due to safety reasons. Safety instructions of the responsible employees must be obeyed.

Advisors: Dr. Astrid Lampert / Miguel Delgado Prieto

(Dr. habil. A. Lampert) (Miguel Delgado Prieto)

Date of issue: 15.01.2020

Due date: 15.01.2020

2 Abstract

Within the framework of this thesis a graphical interface in the programming environment of LabView is to be developed. LabView is a software system of National Instruments which facilitates data acquisition and data control.
The main goal of the project is to visualise outgoings of several sensors related to aeronautics on a panel which analyses the signals and eventually permits to use them for further employments. This implies a selection of sensors which are important in the aeronautic area within previously settled criteria and connecting them to the programming environment. This accomplished a software is to be developed in order to acquire the data of the connected sensors, process and allocate them to further employment. The interface between user and software will be the panel on which the analysed data of the sensors will be represented.
Considering all mentioned above, this project provides students the possibility to gain an inside in the concepts of instrumentation and in the handling of data within a programming environment as LabView.

3 Table of contents

4 Table of figures

5 Table of charts

6 Table of formula

7 Nomenclature

7.1 Latin symbols

Symbol	Unit	Signification
D	/	Duty cycle
G	G	Acceleration value in g
M	g mol^{-1}	Molar mass
Ma	/	Mach number
R	J mol^{-1} K^{-1}	Universal gas constant
RH	%	Relative humidity
T	°C	Temperature
$T_{°C}$	°C	Temperature in Celcius degree
T_K	K	Temperature in Kelvin
ΔT	K m^{-1}	Temperature gradient
T1	ms	On-pulse duration
T2	s	Whole cycle duration
a	m s^{-2}	Acceleration
c	m s^{-1}	Sonic speed
c_v	J kg^{-1} K^{-1}	Specific heat capacity at fixed volume
c_p	J kg^{-1} K^{-1}	Specific heat capacity at fixed pressure
d	°	Position in degree
f	Hz	Frequency
f_{sr}	Hz	Sampling rate
g	m s^{-2}	Acceleration due to gravity
g_i	/	Common weight
h	m	Altitude
h_{ft}	ft	Altitude in foot
h_m	m	Altitude in meter
k	/	Specific heat capacity ratio
n	/	Polytropic exponent
p	kg m^{-1} s^{-2}	Pressure
p_{bar}	bar	Pressure in bar
p_i	/	Value of the individual criterium
pPa	Pa	Pressure in Pa
s	m	Location
t	s	Time
v	m s^{-1}	Velocity
v_g	m s^{-1}	Ground speed
v_{kn}	kn	Velocity in knots
v_v	m s^{-1}	Vertical speed
v_w	m s^{-1}	Wind velocity
x	V	Outcome of the temperature sensor
y	V	Outcome of the pressure sensor
z	s	Pulse duration of the compass sensor

7.2 Indices

General indizes	Signification
d	Down
max	Maximum
u	Up
0	Reference
1	First component of the vector
2	Second component of the vector
3	Third component of the vector

7.3 Greek symbols

Symbol	Unit	Signification
β	/	Exponent in the pressure altitude equation ($\beta = \frac{M \cdot g}{\Delta T \cdot R}$)
ρ	kg m^{-3}	Density

7.4 Acronyms

Abbreviation	Signification
A/D	Analogue/Digital
DAQ	Data Acquisition
EGT	Exhaust Gas Temperature
HIL	Hardware-in-the-loop
I/O	Input/Output
ISO	International Organization for Standardization
MCIA	Motion Control and Industrial Applications
NASDAQ	National Association of Securities Dealers Automated Quotations
NI or NATI	National Instruments
OWA	Ordered Weighted Average
PWM	Pulse width modulation
VI	Virtual Instrument

1. Introduction

Nowadays instrumentation and means for motorization are constantly gaining on importance. Especially in the transportation sector they are becoming indispensable for the correct functionality of technical systems due to the fact that constant information acquisition is required in order to enable the user to make adequate decisions. The latter includes for example decisions about the use of the received information through a digital modulator or about presenting the data on instrumentation panels as it is above all the case in aeronautical sectors. In order to represent this information though, a software and data, which can for instance be acquired by sensors related to a model, are needed.

Against this background the School of Industrial, Aeronautical and Audiovisual Engineering of Terrassa (ESEIAAT) of the Universitat Politècnica de Catalunya started a new series of practical sessions for students respective to an aeronautic subject related to instrumentation and measurement. Sensors of all type are being connected to the software LabView through an acquisition system of National Instruments in order to analyse and visualise data on a panel. In fact, LabView is a system-design platform and development environment for a visual programming that allows a professional deployment of supervision and control systems used across many industries as manufacturing, automotive or aerospace. The project at hand is one of the first of the newly started series. Its underlying motives entail the connection of previously selected sensors related to aeronautics and with different outcomes such as digital, analogue or modular to LabView so that later on every other sensor of the same outcome type can easily be incorporated into the environment. Visualising the data on panels permits not only to express them in an understandable way and to use the offered information for additional or subsequent processes but facilitates above all the replication and simulation of panels of different actual machines. For example, a whole flight control panel as used in airplanes nowadays can be copied.

In summary, instrumentation and measurement systems are increasingly being applied, above all in the aeronautic sector where they are essential to assure a secure process in which not every step has to be or even can be controlled manually. These systems often rely on data acquired through sensors. The data is converted from analogue to digital signals and then processed and visualized on monitors or panels. These are exactly the stages pursued in the present project.

The thesis is structured as following. Chapter 2 gives an insight into the actual researches and application fields of LabView and its possibility to create virtual instruments in front of which background the thesis is elaborated. The following Chapter 3 provides the theoretical background of the software, the sensors and the atmosphere conditions encountered during flight as well as the definition of velocity and acceleration. Next, Chapter 4 demonstrates the steps of selecting the quantity and type of the sensors and the connecting port. The adjacent Chapter 5 describe the functionality of the chosen sensors with regard to the programming of the panel. Chapter 6 elucidates the testing of the right functionality of the hardware before connecting them to the software whose programming as well as the realisation of the visualization panel are shown in Chapter 7. Chapter 8 procures the testing of the software both without connected sensors but with synthetical signals and with connected hardware in order to subsequently test the whole system. A summary as well as an outlook is given in the last Chapter 9.

2. Background and trends

The technical part of this work is related to instrumentation, acquisition and visualization respective to aeronautical application within the programming platform LabView. In this framework the scientific part has to include a vision of further LabView applications in similar or other fields. LabView is a platform used in different areas for different applications of which some will be mentioned followingly. Nowadays virtual instrumentation becomes more and more indispensable in sectors as the transport sectors like automobile, boats and aircrafts or in mechanical industries where engines are used in several machines. For example and above all, virtual instruments are employed in aviation and defense areas. Since both mentioned areas are sectors where high precision, reliability, quality and security is required it is necessary to perform various tests before validating and releasing objects originating from them. Consequently, tests have become an essential marketing aspect for which reason NI specialized in adapting test strategies matching the market requirements. Adaptable electronic and electrotechnical samples are being offered by NI permitting to estimate the development risk of considered objects and to administrate newly defined norms and laws. One of the testing options is called hardware-in-the-loop (HIL) which permits to conduct a test at the beginning of the design cycle. Samplings in aeronautics and defense often result to be very expensive and of high risk if not working properly. Therefore, virtual probes realizable with HIL are a good alternative to real ones, reducing costs, failure and risks and allowing to consider various scenarios and parameters before producing a real probe. Besides mentioned points, the software LabView is applied where radars, electronic war and intelligent signals are concerned. They acquirer and process vast number of signals with different frequencies and characteristics for which a flexible hard- and software system capable of following the development pace is required. NI proposes next to a rapid prototype generation also a stable implementation, flexible validation and reliable testing function fulfilling this requirement. Further, communication and navigation systems are also constantly requested to be improved for which a flexible development and instrumentation system is needed in order to design new systems. Regarding the increasing amount of radio signals used in the everyday life environment and interfering with the electric war and aviation systems, receiving and transmitting clear signals becomes more difficult. The NI platform offers a possibility of creating noise free communication paths through tools capable of rapid signal processing and analyzing. [25]

Since LabView allows real-time acquisition and monitoring both of which are important requirements in aviation it is convenient to use this platform for the programming of a Data Communication and Monitoring System. Besides the possibility to store, analyse and display aircraft parameters it is further possible to perform data transmissions and by this sharing data between different devices. It permits to process the data and to acquire information of aircraft parameters in different ways. Due to providing a human-computer interface the user can survey the parameters and consequently detect faults on early stages and intervene or initiate corrections if necessary. [41]

One field in which LabView's utility has also been discovered and put to practice is the automobile industry. A lot of mechanical parts have a complex structure and their realization is expensive. Above all engines have a complex composition. It is helpful to complete the whole structure based on virtual instrumentation in order to get insight in every part before their actual realization and to register and to pursue important parameters as temperature, fuel consumption and gas emission. Recording those parameters is especially helpful when testing and developing a new engine. Instead of installing measurement and monitoring instrument on a completed engine, software and hardware connected to a computer and based on virtual instrumentation can be used reducing costs and time. Further, while the functionality of hardware instruments is set by the manufacture the programming platform permits by little changes to adapt to the users wishes and necessities. Inclusive during the process the structure and parameters of the tested object can be changed. Instead of procuring new hardware changing the code is sufficient. All is needed is the ability to use programming language. Besides, while different instrumentation is needed for tasks as signal acquisition, processing, analysis, storage and distribution all can be realized within the same programming environment. At the same time communication with other devices is possible. For example, LabView is employed for diesel engines which are operated with diesel-biodiesel blends in order to verify their functioning and characterize them. Since an engine needs several sensors and actuators differing in their communication protocol and signal acquisition a virtual instrumentation seems only logical. Mechanical, electronical as well as computing knowledge all are united in one single program enabling to combine measurement, analysis and control in one software. [33]

A further application field for virtual instruments and the software LabView is the solar photovoltaic module. Nowadays more and more attention is being dedicated to sustainable energy supply. Employing photovoltaic systems, solar energy represents one possibility of producing sustainable energy. Thanks to their low costs, their simple maintenance and installation they have become one of the main emerging technology among the sustainable ones. In order to verify the efficiency and fill factor of these kind of module, a front panel within LabView is programmed to display real-time information about solar radiation, ambient temperature, humidity as well as current, voltage and other kind of data creating a virtual laboratory. Displaying the information on a graphical program facilitates the understanding of the module and its functionality and enables the monitoring of real-time performance as well as making the data accessible. Experiments and studies can easily be fulfilled through this platform besides the fact that the experiments can be performed under less controlled conditions. All this can be used as a tool for the user enabling him to unite theory and practice on real-time instruments. Besides the user can follow the data stream through the program starting by the sensor acquired data, to the collecting and displaying on the front panel in form of graphical indicators or tables. Once the basic program installed the virtual platform system can be adapted to the needs of the user – it can be extended to monitor lager solar modules or to fulfill educational purposes. [39]

Behind this background the LabView environment represents a professional development tool with an essential academic potential. Technologies in both information and electronics keep constantly developing and improving while the digital system of which they are composed and which are running in the background are becoming more complex and larger. Students striving to become engineers or researchers need to confront themselves with the changing technologies. In order to achieve the former, they need to understand the complex coherencies as well as the logical relations assembling the digital systems. For this reason, new teaching or education methods in the classroom are requested. Here is where the programming platform Lab View as well as its application possibility of virtual instruments are gaining on importance. In order to improve the teaching quality in class and learning process of students it has been discovered that active participation in class and active integration of the students during the lecture are of much use. The professor should no longer stand before his students and explaining the new lessons talking in monologue about the themes but the students should interact directly with the new subject matter by putting instantly into practice the newly acquired knowledge. LabView permits a new teaching method based on high technologies where theory and practice can be executed at the same time by applying the theory instantly. The simple and easy structure of the programming platform thanks to the use of familiar icons and thanks to restricted code writing as well as to the numerous available libraries allows student to complete exercises in class as well as to keep practicing on their own after class.

Followingly two examples of instrumental related LabView application respective to didactic and educational purposes are presented. First, the class Digital Logic form the School of Computer Science and Engineering of Qujing Normal University in QuJing (China) which is dedicated to computer and computer related subjects makes use of the programming platform LabView as a virtual teaching platform. A part from applying the learned theory the platform allows students to amplify their knowledge of planning and establishing a systematic concept, designing user interfaces and analyzing the background running system. They learn how to transition from the details to the bigger part and finally to the whole structure. Usually the class would take place in laboratories, where actual hardware equipment would be used for demonstrations. Besides their high acquisition and maintenance costs this equipment also is easily lost and broken. Consequently, the hardware is limited but needed in order to permit students to practice and retrace the learned theory to solve problems in real life. Using LabView as a virtual teaching platform reduce the costs especially respective to maintenance since it is less sensitive to mis-operation, and permits the consolidation of the newly

acquired knowledge with the help of experiments both for class demonstration as for self-learning. [47] The second example is the class Electronic instrumentation from the Department of Electrical Engineering of the Federal University of Maranhão (UFMA) in Brazil which is also proving to become more challenging due to the need to integrate innovative teaching methodologies. Learning methods have to be adapted to the learning objective. In order to increase the students learning retention by giving them the opportunity to participate actively instead of passively in class virtual instrumentation platform are proving themselves useful. The students get an insight in the functionalities of data acquisition and analysis, of virtual instrumentation and system control all in one single platform. Using technologies in order to accomplish informing and communicating between different devices or between computers and users as well as appropriate themselves with ID techniques is made possible. Usually the teacher holds a class by its own while the students listen passively and memorated the heard information in order to later on use the knowledge for projects to be solved after class. Since some students have trouble retaining information through passive listening, they can be discouraged to pursue the class. Using LabView tutorials by for example connecting and testing temperature sensors through which the students can retrace the application on data acquisition create a laboratory environment and motivates the students to apply and reinforce the learned theory. Additionally, tasks can be given to be accomplished at home on their own while an online forum including the teacher assures assistance if help is needed. Further, engineers as well as researchers work with software in order to create and design applications and projects. For this reason, it is useful to familiarize students on an early stage with the functionality of common software and programming platforms. [37]
In this thesis the educational and aeronautic related part is exerted. Thanks to the tutorials and the application of the task students can rapidly gain insight in the functionality of LabView and acquire knowledge about the processing of data within a professional acquisition and instrumentation environment. Further the practical sessions relate to an aeronautic subject about instrumentation with the aim to analyse and visualise the data of different sensors on a panel with the possibility to later on connect every other sensor of the same outcome type to the environment. With little changes every sensor will be able to be visualized on the panel.

3. Theoretical background and materials

This chapter briefly introduces part of the National Instruments technology due to the fact that it is at the origin of the here used programming platform LabView in which environment the final panel is realized. Further, after presenting the programming environment itself it gives a general overview of the definition and different types of sensors in order to better classify the sensors used for this project. Finally, the Standard Atmosphere as well as a definition of velocity and acceleration are introduced since they will be necessary for the calculations and interpretations of the sensor data.

3.1. National Instruments and their software LabView

National Instruments is a stock company specialized in automation and measurement systems related to computers. Its shares can be acquired under the name NATI at the American electronic bourse National Association of Securities Dealers Automated Quotations (NASDAQ). The company was founded in 1976 in Austin, a city in Texas (USA), where its headquarters remain until today. Nowadays the company has communities located all over the world as in France, Italy, Portugal, Turkey, Korea, Japan, China and Spain – the latter one with community quarters situated in Madrid and Barcelona.
In order to allow Scientifics and engineers to easily develop, prototype and implement environments respective to measurement, testing and control through an open platform a great number of different products both in hardware and in software for data acquisition, processing and visualization which can be connected and used by every standard computer is offered. The objective is to promote innovation and discovery in the automation and measurement sectors. [27]
LabView is a software developed by National Instruments which offers a graphical programming environment within the programming language G. The software can be adapted to the user's needs and can be deployed on every common computer. The main difference and advantage to usually employed text-based programming softwares is the additional graphical environment within the same development system specialized for applications in data acquisition, control, analysis and presentation. It allows engineers to create every type of user interface without having to develop a whole new program. Besides, systems written in other programming languages can be incorporated and actualizations for both software and hardware exist.
LabView works with programs called Virtual Instruments (VI) due to the fact that they only represent real instruments without being ones. Those VIs are the user interface between the outside world and the developed program and divide themselves into a front panel, block diagrams and palettes.
The front panel as shown in Figure 1 combines the outputs of the program and the inputs of the user and represents the graphical interface of the VI. It is composed of controls in order to introduce parameters and of indicators in order to display the obtained results. The controls and indicators can adopt different forms such as buttons, graphics, displays etc..

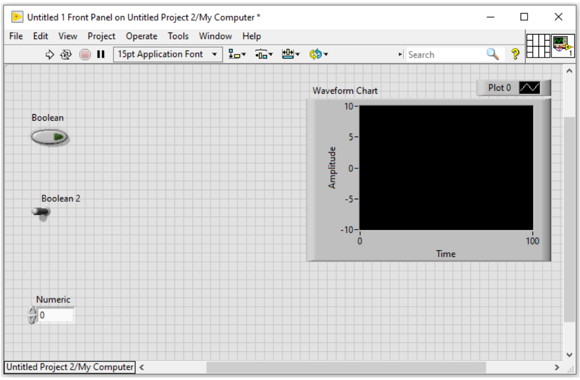

Figure 1 Example of front panel view

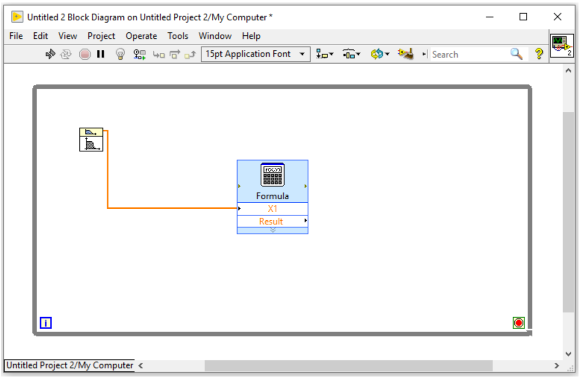

Figure 2 Example of block diagram panel view

Figure 2 shows the block diagram panel, which represents the source code of the VI. The functions and structures used within this part provide from the included program libraries specialized for data acquisition, analyse, control, communication and presentation. Contrary to the usual way of creating a source code by writing down text lines, the source code is created by arranging icons, symbols and other objects and connecting them through cables. The latter represents the trajectory of the data and consist of different colors and styles depending on the data type flowing through them. The objects or structures meanwhile execute the code. The corresponding items appear automatically on the front panel while the block diagrams are arranged and the other way around.

The palettes arrange the tools needed for creating and modifying the code thematically. There are three types of different palettes as illustrated in the following three figures:

Figure 3 Tool palette

The tool palette (Figure 3) which contains general tools for the programming platform, the control palette (Figure 4) which assembles all the controls and indicators for the front panel and the function palette (Figure 5) for the block diagrams. In summary, the principles of programming in LabView consist of choosing the controls and indicators in the front panel and later on connect them through cables in the block diagram after having added further functions and structures. Once the program completed there are two options of starting it. First there is the possibility to run it once and secondly you can make it run continuously. In order to stop the program, there is the possibility to set the simulation on pause and restart at the same point at which one it stopped or to stop it definitively by pressing the corresponding button or by implementing a button for this case on the front panel. The latter option is recommended.

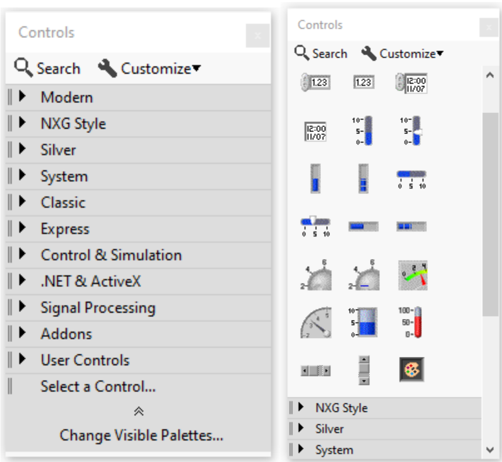

Figure 4 Control palette

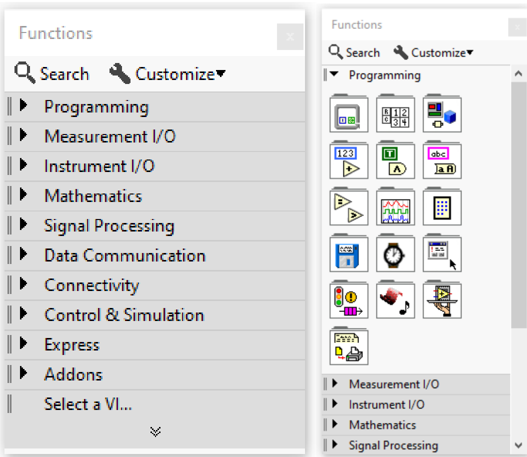

Figure 5 Function palette

The program itself is organized in different rectangular structures which control the flow of information and data. These structures are divided in sub diagrams which contain various cables and terminals. Typical structures are the case structure, the sequence structure, the For Loop, the While Loop and the formula node. The case structure consists of several overlapping sub diagrams. Only one of them is visible and only one is executed at the time depending on the value the selector receives. The most common example is the case structure true or false. Similarly, the sequence structure is arranged in overlapping sub diagrams of which only one is visible at the time. When this structure is used all the sub diagrams are run through respective to their chronological order, starting at number zero and following the growing numbers. The data can be exchanged between the sub diagrams.
The For Loop serves to repeat its contents a defined number of times. There is the option shift register which permits to save the values obtained by several previous interactions. A shift register always shows the previous value on the left side and the actual value on the right side. The While Loop is similar to the For Loop. Both are buckles and both have the option shift register proposes. Whereas the For Loop is executed a defined number of times, the While Loop works after the principle "do… while… is true". Since the value is checked only after the buckle, it is always executed at least once.

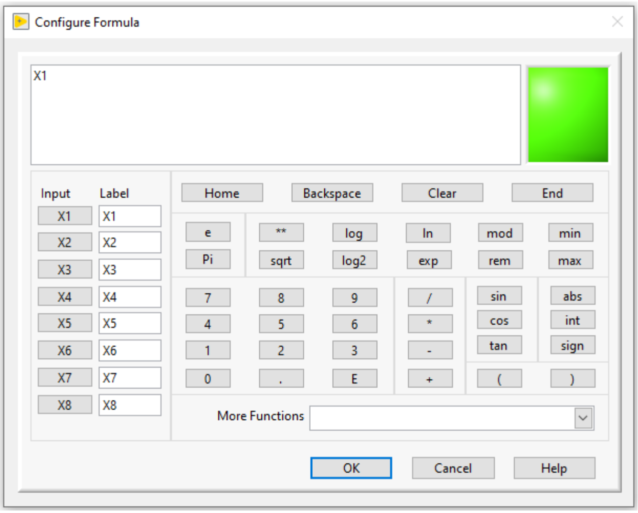

Figure 6 Formula node

Among an extensive set of function blocks available, the formula node pictured in Figure 6 facilitates the implementation of complex equations with several variables. It permits to implement formulas in a direct and orderly way. Every used variable has to be defined as incoming or outgoing even if not all outgoing ones will be used later on and every formula has to be separated by a semicolon. [20]

3.2. Sensors and their categorizations

Water boiler, heart beat measurer, oil level indicator, smoke detector – whether in households, in medicines, in means of transport or in factories, sensors are employed everywhere. They are the interface between the outside world and every type of machinery, making automation engineering possible and reducing the outrange of manual control. Especially in aeronautics numerous processes rely on sensors. Everywhere where data about temperature, pression, positions and fill quantity are needed or an automation process is implemented, sensors are employed.
Sensors are technical devices designed to measure the actual physical or chemical value of the considered variable and placing the acquired data at disposal for further reduction. Their function consists of giving remote indication. The reduction can be pursued manually by a qualified person or digitally by a corresponding program. Consequently, a sensor represents the interface between the

outside world and the reduction system. Its application in order to measure these physical or chemical values is called sensor system. An example for sensor-based systems are feedback control systems. The measured value is constantly being compared to the desired value and according to the discrepancy between the two, correcting actions are being initiated. First, an equalization process starts in order to rearrange the desired value. Secondly, an alarm can be transmitted should the discrepancy be too important to be corrected by the system itself or should an obvious trend be illustrated. Lastly, the system can shut down automatically in order to prevent further damages or destructions should the alarm keep being unattended for too long. [16]

Sensors can be classified respective to different categories. A common differentiation which refers to the distinctive way of sensors of using or producing electrical power is the distinction between passive and active sensors. Active sensors emit electrical signals according to the measured incoming signal for which they do not need auxiliary energy but produce their own tension. Since a static state does not provide any energy active sensors usually measure state changes. Passive sensors in contrary capture and measure incoming signals, transform them into electrical ones and transfer them to a processing system. In order to accomplish this, they need an external auxiliary energy supply which also permit them to measure static states. Light sensors, temperature sensors as well as pressure sensors are typical examples for the former while capacitive and inductive sensors as well as magnetic sensors are examples for the latter. [46]

Another option of categorizing sensors is to differentiate between digital and analogue sensors. The formers are used for switching outgoings and often detect final positions since they only contain information coded into ones and zeros. Analogue sensors can edit various outgoings besides ones and zeros wherefore they can be used for measuring distances and positions. Their outputs can be both a current or a tension output. Usually the tension output reaches values between 0 and 10 V while current outputs differ between 0 and 20 mA. If the outputs are digital, the signals are transferred by busses or synchronous serial interfaces. [13]

In order to better clarify how sensors actually work, two examples of common operation modes will be described followingly. The first usual operation mode is the electromagnetic one. An inductor is exposed to a magnetic field under a determined tension. Every disturbance or deformation of the magnetic field results into a change of tension which is captured by the sensor and translated into a signal. Acceleration and force sensors are examples for sensors working under the electromagnetic mode. A different functionality is used for temperature sensors relying on the bimetallic operation mode. According to a change in the temperature the bimetal will deform in a specific way. If connected to a voltage source the deformation leads to different resistances from which again the importance of the change of the observed value can be deduced and finally be indicated. [16]

In the aeronautic sector sensors need to master high reliability and steadiness as well as resilience respective to a harsh environment. Also, they may be exposed to a wide range of temperature due to altitude changes. Sensors are used for the dynamic of the structure, the flight tests, the chassis, the flume, the engines, the combustor etc.. With them acceleration, pression, vibrations, sounds, strains, turning moments and forces can be captured and surveyed. [32]

3.3. Standard Atmosphere

The Earth's atmosphere is divided into several different layers of which the lowest one reaches up to 11 km and is called troposphere. Due to the weather influence the atmosphere experiences constant changings dependent on time and on the geographical location which are noticeable in the different variables that characterize the atmosphere. The temperature, the wind, the sonic speed, the pressure, the humidity and the density are the most typical variables defining the atmosphere's air state. They are all dependent one from each other in such way as to influence themselves mutually. In order to allow a comparison of atmospheric data independent from the geographical location and the actual

weather, a common basis called the standard atmosphere has been introduced by the International Organization for Standardization (IOS). Especially in the aviation sector it is of high importance to calibrate all the aviation instruments according to the standard atmosphere to avoid misunderstandings between the ground team and the airplanes or the airplanes among each other. The calibration according to the standard atmosphere ensures that all flight instruments of airplanes flying at a similar geographical location and a similar height succumb the same deviation such as to display identic information. Above all for the barometric height after which the airplane's staggering is oriented the comparison is obligatory.
The mayor dependency of the characteristic variables mentioned above is the height as illustrated in Figure 7.

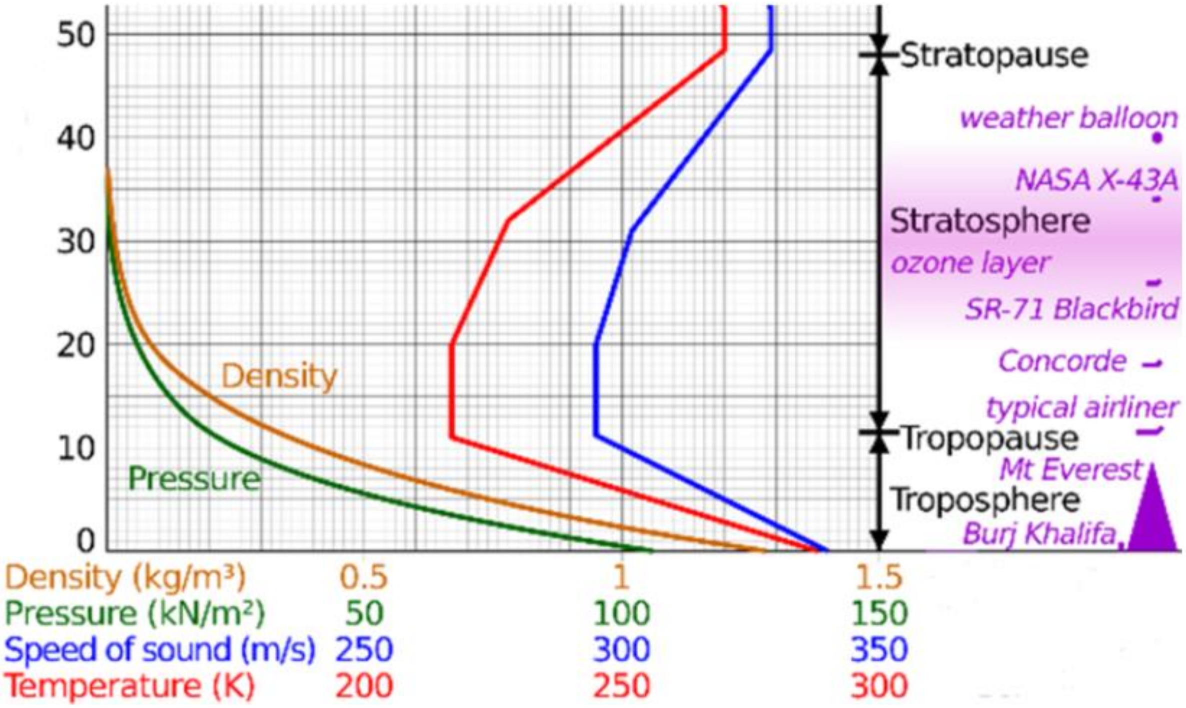

Figure 7 ISO standard atmosphere – characteristic variables [23]

All calculations in aviation are referenced to the value the considered variable is assigned to corresponding to the standard atmosphere at sea level. In the ISO standard atmosphere, the values at sea level are marked with the index 0. They are listed in Table 1.

Table 1 Value at sea level according to the standard atmosphere

Characteristic variable	Value	Unit
p_0	1013.25	hPa
ρ_0	1.225	kg m^{-3}
T_0	288.15	K
$\left(\frac{dT}{dH}\right)_0$	-6.5	K km^{-1}
c_0	340	m s^{-1}
RH_0	0	%

In order to derive the other values from the standard atmosphere starting from the ones at sea level three formulas are needed. The first one is Formula (1), called the polytropic equation, in which the index *u* stands for the word *up* in order to define the value at higher altitude while *d* abbreviates the word *down* for the value at lower altitude. The polytropic equation equalises two ratios. One of them relate the pressure at higher altitude and the one at lower altitude whereas the other one is the ratio of the density in upper height and the one in lower height. The later ratio is elevated by the polytropic exponent. The polytropic exponent *n* adopts a value between 1 and *k* (Formula 2). The former value indicates an isotherm atmosphere – an atmosphere where the temperature is considered constant despite increasing height. The value *k* = 1.4 indicates an adiabatic atmosphere – an atmosphere in which an object transfers from one state into another without interchanging heat with its environment. The third needed formula is the ideal gas law as indicated in Formula (3). Corresponding to this law the pressure can be obtained by the multiplication of the density, the temperature and *R*, which represents the universal gas constant with a value of 8.31432 J (mol K)$^{-1}$. [5, 21]

$$\left(\frac{\rho_u}{\rho_d}\right)^n = \left(\frac{p_u}{p_d}\right) \quad (1)$$

$$1 \leq n \leq k \quad (2)$$

$$p = \rho \cdot R \cdot T \quad (3)$$

3.4. Velocity, acceleration and their correlation

The velocity of an object expresses how fast and in which direction the object changes its actual position in reference to the time for which reason it is defined by its absolute value as well as the direction in which the motion takes place. Consequently, the velocity is expressed as a vector. In the common language the expression velocity is used to refer to one single value, which is in fact not the velocity itself but the norm of the velocity vector. Formula (4) indicates the velocity vector, calculated by the ratio of the distance and the time in which the distance has been covered, while Formula (5) shows the velocity norm, often referred to as velocity. The norm of a vector is defined as the root of the individual squared vector-entries summed up.

$$\vec{v} = \frac{\overrightarrow{ds}}{dt} = \dot{s} \quad (4)$$

$$v = |\vec{v}| = \sqrt{v_1^2 + v_2^2 + v_3^2} \quad (5)$$

The acceleration as described in Formula (6) is defined as the change of motion state of the object which results in a change of the momentary velocity over time. Similarly to the velocity, the acceleration is in fact a vector but often the term is used to describe the norm of the acceleration vector (see Formula (7) below). Note that the formulae refer to the three-dimensional space.

$$\vec{a} = \frac{\overrightarrow{dv}}{dt} = \dot{v} \quad (6)$$

$$a = |\vec{a}| = \sqrt{a_1^2 + a_2^2 + a_3^2} \tag{7}$$

Since the later on chosen acceleration sensor refer to two and not three directions, the actual acceleration norm will be calculated with Formula (8).

$$a = |\vec{a}| = \sqrt{a_1^2 + a_2^2} \tag{8}$$

As demonstrated in Formula (9) the velocity can be obtained by integrating the measured acceleration over time.

$$v = \int_{t_0}^{t_1} a\, dt \tag{9}$$

If the velocity in each direction is required, instead of integrating the acceleration norm, the discrete components of the vector can be integrated separately. As for this, the variables in Formula (10) receive the index 1 or 2 depending on the actual axis.

$$v_1 = \int_{t_0}^{t_1} a_1\, dt \qquad v_2 = \int_{t_0}^{t_1} a_2\, dt \tag{10}$$

4. Instrumentation and measurement platform design

As it has been aforementioned, the main goal of this project is to create an interface in order to visualize data and used them for further actions (e.g. control, monitoring, maintenances, etc.). Therefore, at first point some sensors have to be selected. The following chapters will give an insight into the requirements the sensors have to fulfill, into the process of choosing the type of sensors and finally into the selection of the hardware to buy for both sensors and the connecting port.

4.1. Selection of the type and quantity of sensors

Considering the available acquisition modules and the academic purpose of the platform, some initial consideration was taken into account to face the selection of the sensors:

1 They have to be related to aeronautics, as for example to the flight control or to the maintenance.
2 Different physical magnitudes have to be considered to emulate an instrumentation panel.
3 The entrance can only be analogue (i.e. no digital protocols can be considered).
4 The sensors should differentiate in their outputs to consider diversity in their acquisition and adaption procedures (i.e. analogue, digital or modulated outcomes).
5 Sensors should include necessary electronic to deliver electric outputs.
6 Low cost sensors are preferred.

In order to select sensors related to the aeronautic sector the first question to answer is: Which sensors are used in airplanes? Like explained in the previous chapter there are numerous sensors of every type and kind used in every area of a plane for which reason there is a wide palette of choices.

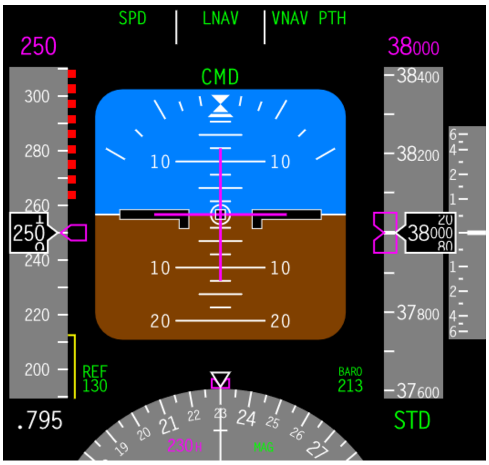

Figure 8 Primary flight display [8]

Figure 9 General aviation instrument panel [43]

One of the most common and indispensable flight control support for pilots is the primary flight display, nowadays arranged in a glass panel (Figure 8). It indicates the position of the airplane in space respective to the horizon and displays the rolling motion. Further, it informs the pilot about the speed of the airplane and its flight altitude.
At the time the primary flight panel was introduced it was not as a glass panel but as a general aviation instrument panel. Where now the digital screens are located there were analog circular indicators as can be seen in Figure 9. Though the design and technology may have been adapted over time the basic

Primary Flight Instruments stay unchanged. There are six different types of them for which reason their entity is referred to as Six Pack. The six instruments are the following:

1. Airspeed Indicator
2. Attitude Indicator
3. Altimeter
4. Vertical Speed Indicator
5. Heading Indicator
6. Turn Coordinator

The information that can be deduced from the displays are essential for the pilot in order to be able to fly safely and keep the control over the airplane. [12] Adequate to its name the Airspeed Indicator displays information about the airplane's velocity measured in knots, a unit defined as following: 1 kn equals 1,852 $km \cdot h^{-1}$ which again equals 0,514 $m \cdot s^{-1}$. There is to make a difference between the indicated velocity and the actual velocity over ground. In fact, the Airspeed Indicator measures the speed of the airplane relative to the surrounding air. In order to obtain the true air speed, the wind's influence needs to be subducted. Initially the position and the acceleration were measured with gyroscopes but nowadays electrical acceleration sensors mostly replace the gyroscopes. In order to define the position in three-dimensional space three piezo sensors are orthogonally arranged – one for each coordinate axis. The speed can be deduced from these acceleration sensors by integrating the value once the data is acquired. It is important to differ between the actual true air speed of the plane and the ground speed. For the latter the wind and the rotation of the Earth have to be considered additionally.

The Attitude Indicator is an artificial horizon indicating the airplane's orientation respective to the actual horizon. It facilitates the location of the airplane's position in space and give the possibility to identify if the airplane is flying upward or down and if the wings are inclined or level.

Third is listed the Altimeter. It depicts the airplane's height respective to the sea level. If the altitude over ground is wanted, the ground level of the momentary over-flown area has to be identified and subducted from the indicated altitude. In order to measure the altitude a barometric pressure system is employed. Thus, the altitude respective to the height above sea-level is deduced from the air pressure outside the airplane and the actual measured data is the pressure – not the height. As the pressure is constantly changing due to the distribution of low- and high-pressure-systems the system has to be adjusted before and during the flight. How to derive the altitude from the pressure is explained later on in Chapter 5.3.

Next comes the Vertical Speed Indicator illustrating the airplane's vertical velocity in Feet Per Minute to give information about the climb and the descend rate.

Another flight support indicator is the Heading Indicator, used to display the main direction the airplane is heading to respective to the horizon system of coordinates or rather the earth fixed coordinate systems. [10] It is a completely gimballed suspended gyroscope whose rotation axis is held perpendicular to the airplane vertical axis by an additional mechanism. Consequently, the rotation axis is constantly located in the level spanned by the airplane longitudinal and lateral axis. In order to avoid important drifts resulting from the Earth rotation or from unbalanced gyroscope parts the Heading Indicator is calibrated with a magnetic compass. During flight the calibration needs to be renewed every quarter hour. The functionality of the gyroscope is based on electricity or on air flow which is bled off a pump connected and operated by the airplane engine.

Figure 10 Compass [7]

Figure 10 shows an example of a flight compass used in airplanes. It indicates the orientation respective to the magnetic poles of the Earth – at least if it is a magnetic compass. Due to the fact that the magnetic poles differ from the geographical one and are in motion, a correction has to be made in order to get the direction respective to the geographical poles. Till today the Earth's magnetic field remains partly unexplained in its physical magnitude. Possibly the convection currents of the Earth's core influence the magnetic field. Thanks to data collection from the space and the Earth's surface the allocation of the magnetic field is well known in spite of its permanent motion and complexity. Generally, the magnetic field can be approached as a dipole of which the magnetic field lines exit the Earth's surface perpendicularly at the magnetic North and South Pole. The penetration points are considered as the magnetic South Pole and the magnetic North Pole which lay inversed to the geographical poles: at the North Pole is located the magnetic South Pole and analogue for the other poles. Further, the poles do not overlap exactly and variate in time. Outside the poles the magnetic field lines exit the Earth's surface under an angel of an absolute value smaller than 90° respective to the horizontal plane.
Figure 11 depicts these differences. [6]
The magnetic field vector consists of a vertical and a horizontal component as illustrated in Figure 12. The angle between the horizontal component and the geographical North Pole is called declination and the angle between the horizontal component and the actual magnetic field vector is the inclination. For this reason, the declination is also known as deviation or variation. A compass bounded to the horizontal plane will orientate along the horizontal intensity. Thus, due to the fact that approaching the magnetic poles the horizontal tendency converges to zero, compasses can barely be used near the magnetic poles. [29]

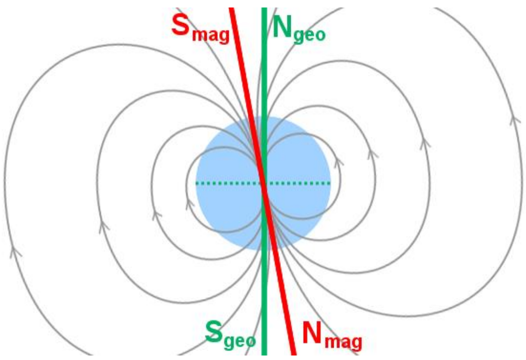

Figure 11 Difference between magnetic poles and geographical poles (excessive eccentricity), [6]

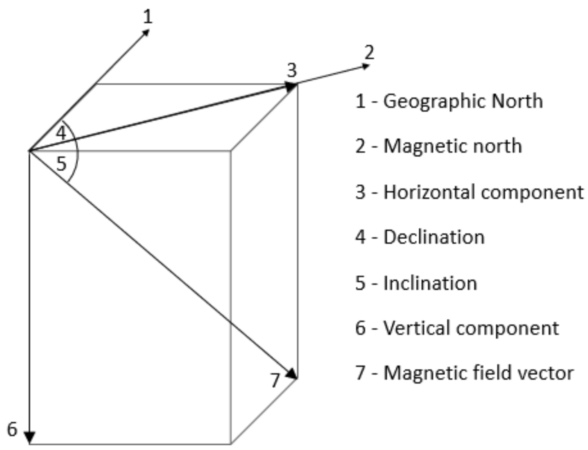

Figure 12 Earth magnetic field vector and its components cf. [17]

Lastly listed above is the Turn Coordinator. This instrument's purpose is to help to fly coordinated turns. It depicts the turn rate, the turn amount and the direction in which corrections have to be applied if necessary, in order to fly coordinatively.
Besides the Primary Flight Display and the compass which are essential for the adequate navigation of airplanes, another important value is the temperature. Not only is the latter necessary to control the passenger's cabin temperature in order to ensure health and comfort but it is also indispensable to keep an overview of the different temperatures in the machinery. Whether the combustor, the engines or simply the lubricating oils – to ensure their right functionality and to enable a secure flight the temperature is a common indicator for the maintenance. In order to give an example for a typical indicator the Exhaust Gas Temperature Margin by which the engine's condition is monitored will shortly be introduced. Exhaust Gas Temperature whose acronym is EGT represents the gas temperature after the turbine. The EGT-Margin is the margin between the actual EGT and the maximal tolerable EGT. An increasing EGT results in a decreasing EGT-Margin and indicates a degradation of the engine's condition. With the ageing of the engine's components the degree of efficiency declines and achieves less thrust with the same amount of fuel. Subsequently, in order to maintain the thrust level more fuel needs to be consumed which results in a higher combustor exhaust temperature and therefore also in a higher EGT. A maximal tolerable EGT has to be defined in order to prevent a thermal overload of the engine. Recapitulatory, the EGT is a measure of efficiency deterioration. [14] This example of the EGT-Margin illustrates clearly that generally measuring the temperature inside the machinery of an airplane is of great importance.
For the reasons mentioned above the following four sensors will be used and connected to LabView: A sensor for acceleration, one for temperature, one for air pression and a compass.

4.2. Selection of the sensors

Once the types of sensors chosen the next task consists in making a choice out of the different supplies accessible at the market.
The temperature sensors differ mainly in the measured medium and temperature range they are designed for. There are different sensors for outside air, cabin air, oil, water, gas, exhaust temperature etc.. The measured medium also implicates certain supplementary properties. If the sensor is in contact with water for example the threat of corrosion or oxidation is higher than if it only measures cabin air for which reason a supplementary protection has to be installed. Further, depending on the sensors' location and functionality they need to withstand a larger or smaller range of temperatures. Sensors inside engines can be exposed to temperatures up to 1200 °C while sensors for oil normally will not exceed 400 °C. Especially after the combustor and the turbine the gas temperature reaches high values. Sensors on the outer surface of the plane have to withstand low temperatures since at a height of 10 km the air temperature is usually around -55 °C. At the same time outer sensors can be exposed to temperatures up to 40 °C for example when the airport is situated in the desert. Should the sensor be located inside a passenger cabin the standard temperature is 20 °C. Consequently, the needed measuring range depends on the area the sensor is used within and has to be considered to assure the sensor is properly working at any time.
Similarly to the temperature sensors, the needed measuring range for the pressure depends on the concerned medium. The pressure of oil, water and air can reach different values. Since the objective is to measure the outside air in order to derive the altitude from the acquired data a small range is sufficient but it needs to be very precise. Considering the standard cruising altitude of approximately 10 km at which the air pressure reaches 0.262 bar and counting on an air pressure of 1 bar at ground level, the range may be small but 0.1 bar of deviation already results in a significate difference of height

as shown in the following. In Table 2 are listed the values of the characteristic atmosphere parameters for the first 11 km of altitude according to the Standard Atmosphere.

Table 2 Standard Atmosphere [9]

Altitude (km)	Pressure (hPa)	Temperature (°C)	Density (kgm^{-3})
0	1013.25	15	1.2250
1	898.75	8.5	1.1116
2	794.95	2	1.0065
3	701.09	- 4.5	0.9091
5	540.2	-17.5	0.7361
7	410.61	-30.5	0.5895
9	307.42	-43.5	0.4663
11	226.32	-56.5	0.3692

With Formula (11) the pressure difference resulting of different heights can be calculated. In order to obtain the result, the pressures values according to the considered altitudes have to be subtracted from each other and multiplied with 10^{-3} if the result's unit is wished to be in bar.

$$p_{bar} = \left(p_{h_1} - p_{h_2}\right) \cdot 10^{-3} \tag{11}$$

The results are listed in Table 3. As can be read 0.1 bar can make a difference of 1 km up to 2 km of altitude.

Table 3 Pressure changes according to altitude differences

Altitude (km)	Difference of Pressure (hPa)	Difference of Pressure (bar)
0 - 1	114.50	0.1145
1 - 2	103.80	0.1038
2 - 3	93.86	0.09386
3 - 5	160.89	0.16089
5 - 7	129.59	0.12959
7 - 9	103.19	0.10319
9 - 11	81.1	0.0811

Since the compass only needs to represent a possibility to indicate the position of the airplane relative to the magnetic poles a simple magnetic compass should be sufficient.
Airplanes can reach a high acceleration up to 8 to 10 meters per seconds. This will not be replicable in the given laboratory for which reason an acceleration sensor with a smaller range can be used with the optional possibility to amplify the signal later on.
It is to be noted that the project aims to emulate a real system for academic purposes. Using aeronautic sensors exceed by far the financial possibilities and is above all unnecessary for the purpose of this project. In order to represent the real system as best as possible references as basic ranges and accuracy may be taken into account. [1]
All sensors are wished to be low cost. Further, all sensors need to have an analogue input due to the accessible equipment. Also, they should be in stock of the firm in order to assure that they can be delivered immediately. Based on these requirements and the information mentioned above the sensors from which has to be chosen of are the following ones. For the pressure sensor the options are the MPX5700DP and the Absolute Gas Pressure Sensor. The first one is a version of the

semiconductor sensor series MPX5700 from the company Freescale. It is a piezoresistive temperature compensated and calibrated silicon pressure sensor conditioned with an on-ship signal. It offers an output signal proportional to the applied pressure comparing it to a reference pressure and is applicable in different areas but above all in analogue and digital inputs ones. [11] The Absolute Gas Pressure Sensor is a sensor from the company Phidgets which measures the absolute pressure of the environment. It can be connected to any device as long as it has an analogue input. [35] Regarding the acceleration sensor the options are the sensor Memsic2125 G/H and the sensor ADXL335. Memsic2125 G/H is a dual-axis accelerometer from the company Parallax Inc.. Not only does it offer the option to measure acceleration on two axes but also it is able to measure vibration, tilt and rotation. Besides the usual way to acquire the signal through a I^2C port, it further offers the option to acquire the signal through a Pulse Width Modulation (PWM) signal. [31] PWM is a modulation in which an incoming technical signal, in our case the voltage, is sampled a concrete number of times by turning the connection between supply and load on and off. This permits to reduce the delivered average power and results in a signal alternating between two values – on rectangular signal going high and one rectangular signal going down. Should the frequency be constant, the rectangle's width is the changing factor. The ADXL335 from the company Analog Devices Inc. is a three-axis accelerometer able to measure acceleration both the static and the dynamic one. [3] CMPS03, Modern Robotics and Phidget1108 are the three options for the compass. CMPS03 is a compass module composed of the magnetic field sensor KMZ51 from the company Philips. Due to its sensitivity it is able to detect the Earth magnetic field for which its purpose as a navigation aid can be fulfilled. The direction the compass is oriented to is coded in one single number: the width of a PWM signal. [36] The Magnet Sensor from Modern Robotics Inc. measures the field strength according to the distance between the sensor and the detected magnetic field. The north pole of the considered magnet results into an increasing value while a decreasing one represents the south pole. [22] Third, Phidget1108 is a sensor from the company Phidget Inc. relying on the hall-effect and returning a value proportional to the applied magnetic field. Besides being able to measure magnetic field it can also give information about the proximity of one. [34] A hall-effect describes the incidence of a voltage resulting from an electrical conductor located inside a magnetic field and through which electrical current is flowing. Last, there are four options for the temperature sensor. First and second are LM35DZ and LM35. They originate from the LM35 series of the company Texas Instruments and are precision sensors equipped with an integrated circuit. Their voltage output is proportional to the applied temperature in Centigrade. One of the two mentioned sensors is the basis of the series while the other one is a variation of the basic sensor. Their differences can be seen in Table 7. [44] TMP36 is the third option. This sensor is a precision temperature sensor from the company Analog Devices Inc. whose voltage output is also proportional to the Centigrade temperature. It is compatible with the first two mentioned options and mainly differs from them in the temperature range as can be seen in Table 7. [4] Forth and last is the Analogue Temperature Sensor Modul from the company SunFounder which has the particularity to be able to output digital and analog signals simultaneously. [42]

In order to correctly choose a sensor and define the best option out of several choices considering all given properties the multi-criteria method named Ordered Weighted Average is used. This method weights all the criteria and organizes them according to their average.

Making decisions normally follows a certain sequence of steps. First, some alternatives conform to the basic requirements are being chosen. Next, a list of criteria which has to be considered for the evaluation of the alternatives is set up. Each of the criteria has to be weighted according to its importance for the selection which has to be made. Fourth, a general scale for the evaluation is defined by which each alternative is graded respective to all given criteria. This done a selection method can finally be applied and consequently the best alternative can be chosen. The selection method Ordered Weighted Average follows the same pattern. It starts with the definition of the criteria by which the alternatives should be rated. The number of criteria receive the variable *n*. According to the importance of the considered criteria each is assigned with a common weight g_i. Afterwards the actual individual criterium of each alternative is rated with the value p_i. This accomplished the relative grade is calculated out of the multiplication of the common and the individual weight. The sum of the latter is divided by the product of the highest individual weight and the sum of all the common weights. This calculation summed up in Formula (12) is consequently the ratio between all weighted marks for each item and the highest possible rating. The result is the Ordered Weighted Average (OWA). [45]

$$OWA = \frac{\sum_{i=1}^{n} p_i \cdot g_i}{p_{max} \cdot \sum_{i=1}^{n} g_i} \quad (12)$$

In our case 4 different sensors have to be chosen, each of them having two to four alternatives and being compared in n = 7 different product characteristics. The weights are assigned from 0 to 10 as followingly explained: The output is the most important characteristic since it is primary for the connection to the system and since we are searching different outputs so as to avoid having the same operating system for all sensors. Next in rating is the operating voltage. The given connecting system has a limited voltage the sensor can be fed with for which reason the sensor will not work properly if the needed voltage is too high. The price is third in ranging due to the financial resources assigned to this project. Forth comes the range followed by the accuracy or error, the sensivity and the operating temperature. All these last characteristics are not essential for the working of the sensor itself. They are important in order to ensure the acquisition of correct data and to make sure the sensors are sensitive enough for the given conditions in the laboratory. Since the temperature sensor is measuring temperature itself, the characteristic operating temperature is synonym to the range and therefore fall away (n = 6). Now the alternatives can be rated from zero to five respective to each other and to the wished qualities and the OAW can be calculated. Each OAW is rounded to the second decimal place. Table 4, Table 5, Table 6 and Table 7 list the weighting of the different criteria and the value of the individual criterium of each alternative as well as the final OWA.

Table 4 Ordered Weighted Average - Pressure sensor

Criteria	Weight	MPX5700DP			Absolute gas pressure sensor		
	G	P	P x G		P	P x G	
Output	10	5	50	Analogue	5	50	Analogue
Operating voltage	9	4	36	4.75 V to 5.25 V	4	36	4.8 V to 5.3 V
Price	8	4	32	11.71 €	2	16	28.00 € (33.32 €)
Range	7	5	35	0 kPa to 700 kPa	3	21	20 kPa to 400 kPa
Measurement Error Max	5	3	15	± 2.5 %	4	20	± 1.5 %
Sensivity	5	3	15	6.4 mV kPa^{-1}	0	0	No data
Operating temperature range	3	5	15	-40 °C to 125 °C	5	15	-40 °C to 125 °C
Sum	47		198			158	
OWA		**0.84**			**0.67**		

Table 5 Ordered Weighted Average - Acceleration sensor

Criteria	Weight	Memsic2125 G/H			ADXL335		
	G	P	P x G		P	P x G	
Output	10	5	50	PWM	4	40	Analogue
Operating voltage	9	5	45	3.3 V to 5 V	5	45	1.8 V to 3.6 V
Price	8	2	16	26.27 € (31.26 €)	4	32	13.11 € (15.60 €)
Range	7	5	35	± 3 g	5	35	± 3 g
0 g Offset over Temperature	5	3	15	± 1.5 mg $°C^{-1}$	4	20	± 1mg $°C^{-1}$
Sensitivity Change Due to Temperature	5	4	20	± 0.02 % $°C^{-1}$	5	25	± 0.01 % $°C^{-1}$
Operating temperature range	3	3	9	0 °C to 70 °C	5	15	-40 °C to 85 °C
Sum	47		190			212	
OWA		**0.81**			**0.90**		

Table 6 Ordered Weighted Average - Compass

Criteria	Weight	CMPS03			Modern Robotics			Phidget 1108		
	G	P	P x G		P	P x G		P	P x G	
Output	10	5	50	PWM signal	5	50	Analogue	5	50	Analogue
Operating voltage	9	5	45	5 V	5	45	0 V to 5 V	5	45	4.5 V to 5.5 V
Price	8	5	40	Already available	4	32	20.13 € (23.95 €)	5	40	6.20 € (7.38 €)
Range	7	5	35	1 ms to 36.99 ms	3	21	0 to 700	3	21	500 G Magnetic Flux
Accuracy	5	3	15	1 µs resolution; To be sure: 0.1° (10 µs)	3	15	± 2°	4	20	± 0.5 %
Sensivity	5	0	0	No data	0	0	No data	0	0	No data
Operating temperature range	3	0	0	No data	0	0	No data	5	15	-20 °C to 85 °C
Sum	47		185			163			191	
OWA		**0.79**			**0.69**			**0.81**		

Table 7 Ordered Weighted Average – Temperature sensor

Criteria	Weight	LM35DZ			LM35			TMP36			Analogue Temperature Sensor Modul		
	G	P	P x G		P	P x G		P	P x G		P	P x G	
Output	10	5	50	Analogue	5	50	Analogue	5	50	Analogue	5	50	Digital, analogue
Operating voltage	9	4	36	+35 V to −0.2 V	4	36	+35 V to −0.2 V	5	45	2.7 V to 5.5 V	5	45	3.3 V to 5 V
Price (with tax)	8	5	40	2.80 € (3.99 €)	5	40	3.28 € (3.90 €)	5	40	2.54 € (3.02 €)	5	40	5.38 € (6.40 €)
Range	7	3	21	0 °C to +100 °C	5	35	-55 °C to +150 °C	4	28	-40 °C to +125 °C	5	35	-55 °C to 150 °C
Accuracy	5	3	15	± 0.6 °C to 1.5 °C	4	20	± 0.4 °C to 1.0 °C	2	10	± 2 °C	5	25	± 0.5 °C
Sensivity	5	5	25	10 mV °C^{-1}	5	25	10 mV °C^{-1}	5	25	10 mV °C^{-1}	0	0	No data
Sum	47		187			206			198			195	
OWA		**0.80**			**0.88**			**0.84**			**0.83**		

According to the OAW the best choices are as following: MPX5700DP for the pressure sensor (Figure 13), ADXL335 for the acceleration sensor, LM35 (Figure 15) for the temperature sensor and Phidget 1108 for the compass. Since the compass CMPS03 rank behind Phidget 1108 by only 0.2 and is already available and since it is probable that the Phidget 1108 will not be sensitive enough to capture the data of the magnetic earth field, it has been decided to stay with CMPS03 (Figure 16). Also, the latter has a PWM output which has to be modulated and by this differs from the other choices with analogue outputs. This point is also the reason for which Memsic2125 G/H (Figure 14) will be employed instead of ADXL335 even if the ranking stands 0.9 lower.

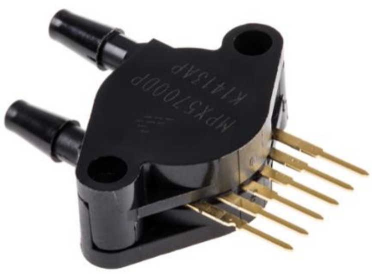

Figure 13 Pressure sensor [40]

Figure 14 Acceleration sensor [30]

Figure 15 Temperature sensor [2]

Figure 16 Compass sensor [19]

4.3. Connecting port

Now that the sensors have been chosen, an acquisition card is needed in order to connect the sensors to the LabView environment, running on a computer. The in the laboratory available acquisition card is the card PCI 6014 from National Instruments equipped with analogue inputs (Figure 17). An external input/output (I/O) card of the type CB-68LP serves to connect the entrances of the analogue/digital (A/D) card. Figure 18 demonstrate the definition order of the pins.

Figure 17 NI PCI 6014 [28]

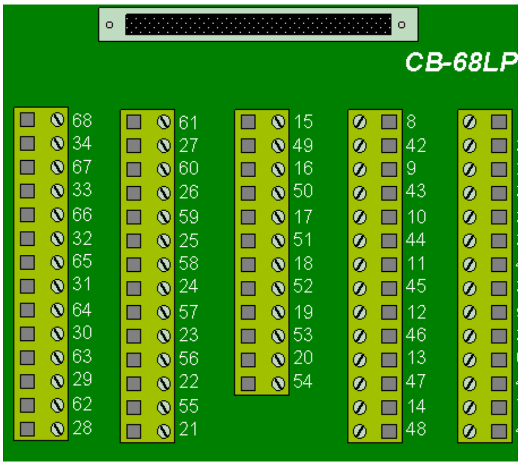

Figure 18 External acquisition card CB-68LP [15]

The NI PCI 6014 card is a digitally triggered 16-bit resolution multifunction data acquisition board with 16 analog input channels and 8 digital I/O lines. It can be operated on every system running with Linux, Windows 2000 or newer or Mac OS. [24]

5. Design of required processing procedures for selected sensors

In this chapter the chosen sensors are shortly introduced and their functionality is explained. Further the integration of the sensors in the actual program is clarified to the point of the final panel which should resemble as far as possible a real general aviation instrument panel. It shall be pointed out here, that if later on while testing the sensors' functionality an offset should be noticed, this offset will be subtracted of the corresponding value obtained by the sensor before any further calculation or conversion takes place.

5.1. Temperature sensor

The LM35 temperature sensor is a linear sensor designed to measure ambient air temperature within a range of -55 °C and 150 °C. It is a precision integrated-circuit temperature sensor, based on a semiconductor and using a voltage output. The latter one is directly proportional to the ambient temperature in Celsius degree. Since the scale of Centigrade is smaller than the one of Kelvin, the voltage output can be reduced. Without any external calibration the sensor has an accuracy of ±3⁄4 °C over its full range and an accuracy of ±1⁄4 °C at room temperature. Due to the low power consumption of only 60 µA it has a low self-heating of maximal 0.1 °C in still air. Every 10 mV equals one Celsius degree. Therefore, the obtained value *x* from the sensor needs to be multiplied with 10^3 in order to obtain the value in mV and then the result has to be divided by 10 so as to get the temperature in Celsius degree (Formula 13).

$$T_{°C} = x \cdot 10^3 \div 10 = x \cdot 10^2 \quad (13)$$

If the surface temperature of the considered object is the same as the ambient temperature, the sensor can be glued to the surface and render the surface temperature with an accuracy of 0.01 °C. Should surface and ambient temperature differ, the sensor will return an intermediate value. In order to avoid this effect, the wiring leading from the device to the LM35 should be insulated by a bead of epoxy from the surrounding whose temperature is not wished to measure. This ensures that the temperature of the object and the temperature of the wire both are the same. In order to measure the temperature of liquids and the like, the sensor has to be mounted inside a sealed-end metal tube while additional coatings are being applied, ensuring that all wiring and circuits are kept dry to avoid corrosion or other effects which could damage the sensor and inhibit its right functionality. [44]
Since the temperature in aviation often is indicated in Kelvin, the obtained temperature will be converted from Celsius degree to Kelvin with Formula (14). For this the measured temperature needs to be added to 273.15 K due to the fact that 1 °C equals 273.15 K.

$$T_K = T_{°C} + 273.15 \quad (14)$$

5.2. Acceleration sensor

The sensor Memsic2125 G/H measures the acceleration of the considered object. Since the objective is to display the speed of the object, some conversions have to be made. But first, both the sensor itself and its functionality will be introduced.

The sensor is a dual axis accelerometer without any moving parts. It is based on a monolithic CMOS IC and processes the received information with an on-chip mixed mode signal. It continuously performs a self-test and is compensated to not lose its accuracy for temperature changes. The sensor has the ability to capture information about dynamic and static acceleration within a range of ±3 g. The most common dynamic acceleration is vibration and the usual static acceleration is the gravity. The measurement system is based on heat transfer by natural convection. Thanks to the use of gas proof mass instead of solid proof mass the system disposes of stiction. It proceeds a respective to the period pulse width-based signal which is proportional to the agent acceleration and is omitted out of two digital outputs. If there is no acceleration the digital outputs perform 50 % of the duty cycle. In the center of the chip over a cavity is located the heat source surrounded by four equally distanced thermocouples. With lacking acceleration, the temperature spreads symmetrically in the cavity, so the temperature gradient and therefore the measured temperature by the thermocouples is the same everywhere. Consequently, the same voltage is transferred to the outputs. As soon as an acceleration takes place the temperature field is disturbed due to free convection heat transfer. The followingly asymmetrical temperature profile results in different voltage outputs directly proportional to the agent acceleration. Since the sensor is a dual axis accelerometer, two of the thermocouples lead to the signal paths for the x-axis and the other two lead to the one for the y-axis. The sensor is sensitive to every change in position and tilt as long as the sensor's position is parallel to the Earth's surface or perpendicular to the gravity field. For this reason, not only horizontal or vertical acceleration can be measured but also inclination movements. For the latter the force of gravity is used as a reference in order to deduce the inclination angle. Should the sensor's axis be orientated perpendicular to the Earth's surface and therefore parallel to the gravity force field, the inclination of the considered object is more difficult to measure.

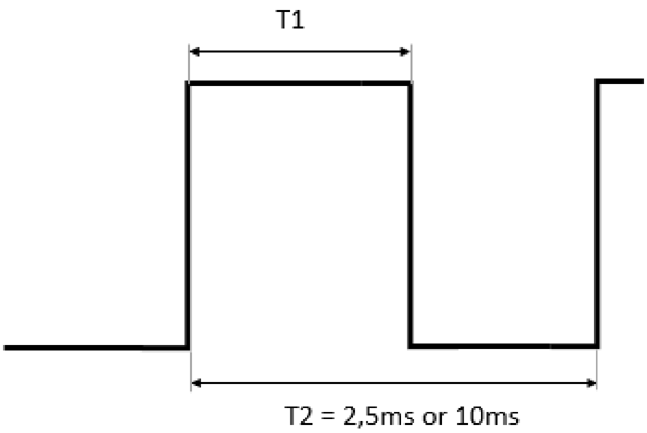

Figure 19 Output PWM signal of the acceleration sensor cf. [31]

The width-based signal is coded like followingly explained. A whole cycle *T2* consist of the actual measured on-pulse *T1* added to the signal going low to zero in-between two measured pulses. Depending on the sensor request form the company *T2* lasts 2.5 ms or 10 ms which equals 400 Hz and 100 Hz if converted. In our case the latter one has been chosen. *T2*'s width is always constant. Figure 19 is a schematic illustration of the cycle. As already mentioned, the cycle is set to 50 % if no acceleration is acting. Otherwise the acceleration is proportional to the ratio *T1/T2* for which reason only the width of *T1* has to be identified while the width of the low going signal is not needed. With Formula (15) the acceleration can be calculated out of the pulse duration. *T1* only needs to be divided by 10 ms.

$$a = \frac{T1}{10 \cdot 10^{-3}} = \frac{T1}{0{,}01} \tag{15}$$

Since the output is digital and an analogue one is needed the output has to be converted. This can be realized by integration with a filter. Another possibility to convert the acquired signal into the requested value is to use the duty cycle. According to the data sheet a duty cycle of 50 % correspond 0 g. Since the sensitivity amounts 12.5 % of duty cycle per g within a measuring range of -3 g to +3 g, 12.5 % of duty cycle corresponds -3 g and 87.5 % corresponds +3 g. Consequently, the value of the duty cycle *D* multiplied by 0.08 and subtracted by 4 returns the acceleration value *G* in g (Formula 16). The latter option is used in the block diagram program. [31]

$$D \cdot 0{,}08 - 4 = G \tag{16}$$

Now the point mentioned at the beginning of this subchapter will be elaborated. A flight panel in an actual airplane does not indicate only the acceleration itself. It indicates the airspeed, the airspeed as Ma number, the autopilot speed, the vertical speed and the ground speed. In order to obtain the different speeds of the considered object the received data from the acceleration sensor has to be converted. The autopilot speed is a value predetermined by the autopilot itself, so there are no conversions or transfers to be made respective to the extent of this project.

The values the sensor is transmitting have the unit g. g defines the acceleration due to gravity which amounts approximately 9.81 m s^{-2}. This means that in order to obtain the acceleration in m s^{-2} the given value has to be multiplied by 9.81. Afterwards the new value can be integrated and the velocity can be obtained with the value m s^{-1}. Consequently, the variable *a* has to be replaced by a_{new} (Formula 17) in all previous formulae. Only than the airspeed, the velocity respective to the medium air, can be correctly indicated. In aviation the velocity often is referred to in knots (kn). Knots is another unit – 1 kn equals 0.514 m s^{-1}. Thus, in order to obtain the airspeed in knots its value has to be divided by 0.514 m s^{-1} conform to Formula (18).

$$a_{new} = a \cdot 9.81 \tag{17}$$

$$v_{kn} = \frac{v}{0.514} = v \cdot 1.94 \tag{18}$$

Since in airplanes the velocity is also indicated in the dimensionless Mach number *Ma* another transformation has to take place. Formula (19) defines the *Ma* as the quotient of the actual velocity of the object and the sonic speed. The latter changes its value according to the height the object is flying in. For this reason, we first need to detect the altitude, then derive from the altitude the actual sonic speed and only subsequently we can calculate the Mach number.

$$Ma = \frac{v}{c} \tag{19}$$

For the vertical speed the vertical component of the velocity vector is need. The vertical speed indicates the velocity by which the object is descending or climbing. In airplanes this value is displayed with the unit feet per minute (f min^{-1}). Due to the fact that the velocity vector has the unit m s^{-1} the corresponding component of the vector has to be converted. 1 meter equals 3.28 feet, and 1 second is 1/60 min. Consequently, the vector's component has to be multiplied by 3.28 and by 60 conform to Formula (20). The use of the component v_2 for the vertical speed implies that the dual axis sensor has to be oriented as followingly: the first axis is orientated parallel to the Earth's surface while the second axis is perpendicular to the Earth's surface.

$$v_v = v_2 \cdot \frac{3.28}{\frac{1}{60}} = v_2 \cdot 3.28 \cdot 60 = v_2 \cdot 196.8 \tag{20}$$

The last speed indicated in an airplane is the ground speed v_g. This speed is the velocity of the object respective to the ground. Its value differs from the measured airspeed according to the wind velocity if existent. Should the wind come backwards, the ground speed equals the sum of the airspeed and the wind speed (Formula (21), left). If the wind comes from the front it has to be subtracted from the airspeed in order to obtain the ground speed (Formula (21), right). It will not be able to measure this kind of velocity in the laboratory for which its mentioning here is exclusively for the sake of completeness.

$$v_g = v + v_w \qquad\qquad v_g = v - v_w \tag{21}$$

It has to be mentioned that by integrating the acceleration over an undefined amount of time in order to get the velocity a constant of integration appears in the result. This constant cannot be determinized with the help of the actual sensor if the situation is a flying airplane. Due to this fact the usual measurement method in airplanes to measure the velocity is by using a pitot tube. A pitot tube is a L-shaped cavernous tube mounted as an obstacle to the present fluid current in order to define the actual total pressure. To measure the velocity a static sounding rod is added to the tube. If the constant is set to zero which means no initial velocity while starting the measurement process the sensor can still release correct values. Further, since the sensor is a dual axis one and the vertical velocity can be measured using the data of one axis, the sensor must be collocated on a gimbal so as to assure its axis are always orientated correctly.

5.3. Pressure sensor

With the pressure sensor MPX5700DP the actual height of the considered object can be determined. It issues a linear voltage output directly proportional to the acting pressure. For this the sensor consists of a pressure side and a vacuum side. An increasing pressure respective to the vacuum expresses itself in an increasing voltage output as does an increasing vacuum respective to the pressure. The pressure reference is the vacuum side, like pictured in Figure 20.

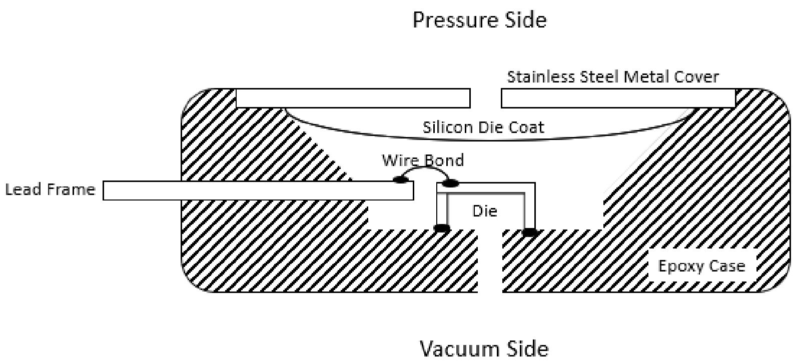

Figure 20 Schematic sketch of the pressure sensor cf. [11]

The pressure sensor consists of a voltage diffused semiconductor strain gauge enveloped in a thin membrane. Depending of the agent pressure the membrane experiences a deflection which is captured by the sensitive strain gauge and converted in an electrical output signal. The latter one is directly proportional to the measured pressure. Even if there are no thermal expansion differences between the membrane and the strain gauge due to the fact that the latter is an integral part of the former, the strain gauge itself is sensitive to temperature changes. In order not to receive falsified data due to temperature influences, a compensation with additional resistive components has to be made as long as a wide temperature range will be applied. In order to protect the sensor and wires, they are wrapped in a silicone gel, insulating them from the environment while still permitting the pressure signal to be transmitted to the membrane.
Each 6.4 mV equals 1 kPa. Thus, in order to obtain the pressure in Pa, the value *y* given by the sensor needs to be multiplied with 10^3 so as to obtain the value in mV and then divided by 6.4 in order to obtain the value in kPa. The result can be multiplied with 10^3 so the unit is Pa (Formula 22). Since in aviation the pressure uses to be indicated in bar the former result can be converted to the new unit with Formula (23) by multiplying the value with 10^{-5}. [11]

$$p_{Pa} = y \cdot 10^3 \div 6.4 \cdot 10^3 = y \cdot 10^6 \div 6.4 \tag{22}$$

$$p_{bar} = p_{Pa} \cdot 10^{-5} \tag{23}$$

The objective is to display the altitude of the object in order to give a reference and navigation aid respective to the ground. Consequently, the height needs to be derived from the data given by the pressure sensor which can be achieved due to the fact that both the pressure and the altitude are dependent one from each other. Formula (24), known as pressure altitude equation, shows how to derive the pressure dependent from the height. The ratio of the temperature gradient is multiplied with the vertical height and divided by the temperature reference. After subtracting the outcome from 1 and exponentiate it with β, the outcome is multiplied with the reference pressure in order to obtain the pressure at the indicated height. The exponent β is the ratio of the product of the acceleration due to gravity and the molar mass of the medium as well as the product of the temperature gradient and the Universal gas constant.

$$p(h) = p_0 \cdot \left(1 - \frac{\Delta T \cdot (h - h_0)}{T_0}\right)^{\beta} \quad \text{with} \quad \beta = \frac{M \cdot g}{\Delta T \cdot R} \tag{24}$$

If now the reference is set to sea level, h_0 adopts the value zero, while p_0 and T_0 adopt the values at sea level according to the Standard Atmosphere. After converting the formula above in order to derive the height according to the pressure we obtain Formula (25). [18]

$$h = \frac{T_0}{\Delta T} \cdot \left[1 - \left(\frac{p(h)}{p_0}\right)^{\frac{1}{\beta}}\right] = \frac{288.15\,K}{0.0065\,\frac{K}{m}} \cdot \left[1 - \left(\frac{p(h)}{1013.25\,hPa}\right)^{\frac{1}{5.255}}\right] \tag{25}$$

In an actual airplane besides the altitude, which can approximately be calculated like shown above, the autopilot altitude and the altimeter correction setting are displayed. The former is a value predetermined by the autopilot itself, so there are no conversions or transfers to be made respective to the extent of this project. The latter is needed because of the fact, that the value of all atmosphere

variables and data are constantly changing and depend on several not influenceable factors, so that in order to calculate the wished value some simplifications have to be made. The Standard Atmosphere itself for example is already a simplification. Therefore, the calculated values always differ even if only slightly from the veritable ones. In order to eliminate the most important deviations some calculative corrections can be made and the outcome is the altimeter correction setting. Since the tools for these corrections are not available and since they would outreach the extent of this project the altimeter correction setting will not be considered.
Feet is a common unit used in aviation for which the altitude will also be indicated in Feet. With Formula (26) the height can be converted from Meters to Feet by multiplying the value with approximately 3.28 due to the fact that 1 Meter equals 3.28 Feet.

$$h_{ft} = h_m \cdot 3.28 \tag{26}$$

5.4. Compass sensor

The compass CMPS03 is a digital and manual compass module with a sensitivity high enough to measure the magnetic field of the Earth. This characteristic is possible due to the magnetic field sensors of Philips KMZ51 the CMPS03 is composed of. In order to detect the horizontal component of the Earth magnetic field and thereby indicating the navigation course of the object, two of these magnetic field sensors outputs are oriented at right angles respective to each other.
The compass has the particularity to offer two different ways of getting the data: a PWM signal and an I^2C interface. Since an analogue input is needed the PWM signal will be used and only this one will be explained in the following. The PWM signal is a pulse generated by a 16-bit timer ranging from 1 ms to 36.99 ms. The lowest value represents 0° while the highest values represents 359.9°. For consequence each degree is coded by 100 µs additional to 1 ms of offset. Between the pulses the width modulated signal goes down to zero for 65 ms. Consequently, a cycle time is formed by the 65 ms added to the pulse width. That means that contrary to the acceleration sensor where the cycle time's width is always constant, the compass sensor's constant is the width of the low going signal not of the cycle time. Figure 21 demonstrate the codification of the direction. Only the positive values of the PWM signal emitted by the sensor output indicate an actual angle of the compass. Though the processor offers a 1 µs resolution, it is recommended to measure at the maximum up to 10 µs, which represents 0.1°. Even if not used each signal is converted due to the lack of synchronization between the output and the conversion. To conclude this compass module design is a simple aid to navigation since it codes the direction the object is facing in a unique number. [38]

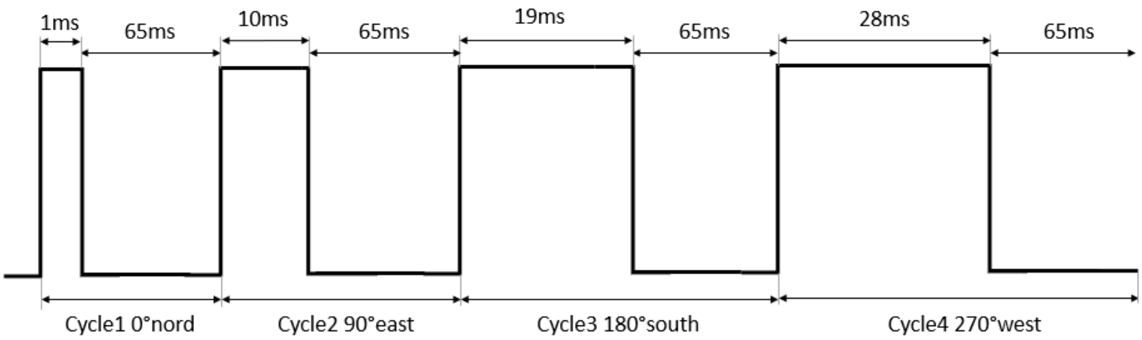

Figure 21 Output PWM signal of the electronic compass cf. [15]

In order to calculate the position *d* of the considered object in degrees after obtaining the pulse duration in seconds, Formula (27) has to be applied. 0.001 is subtracted from the pulse duration *z* and the result is multiplied with 10000.

$$d = (z - 0.001) \cdot 10000 \tag{27}$$

6. Testing of the sensor's functionality

Respective to the aim of joining sensor and software, once the sensors obtained their functionality has to be validated first, for which they need to be connected to a supply source. In order to accomplish this, they are soldered to a breadboard. Since the acceleration sensor has to be moved quickly and the compass sensor has to be tilted in different directions in order to variate the degrees both are mounted on separate breadboards (Figure 23) while the temperature and the pressure sensor are brazed to the same breadboard (Figure 22).

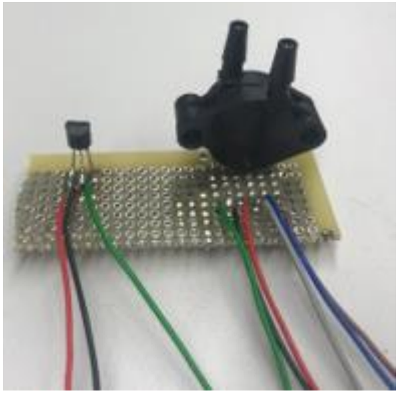

Figure 22 Breadboard with the temperature sensor (left) and the pressure sensor (right)

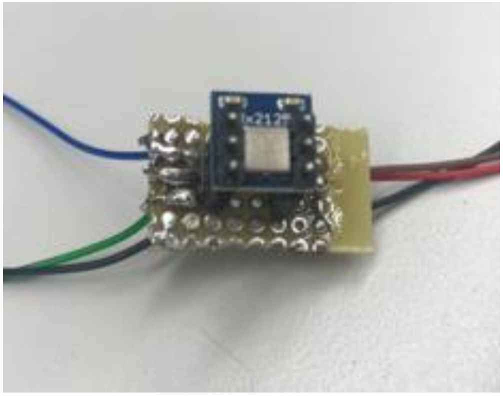

Figure 23 Breadboard with the acceleration sensor

Next, cables are sweated to the breadboards – one for each signal. To avoid confusions or mistakes and to permit to quickly detect malfunctions respective to which signal channel is not working should this case occur, each signal pin from the same sensor obtains a different cable color. Due to the pressure sensor having six different signal pins at least six colors are needed. Corresponding to the usual convention the color black is assigned to the ground cable while the one for the supply obtains the color red. Green is decided to be generally used for the main outgoing signal. All other pins receive random colors – blue, grey, brown. In order to know which pin corresponds to which signal the sensors' datasheets in which the pins are described have to be consulted. Since the acceleration sensor has two main outgoing signals, one is assigned the color green the other one the color brown.
After having soldered cables and sensors to the breadboards and having linked them one to another each connection is tested with the help of a multimeter. In order to ensure the channel continuity, different channel links are not allowed to touch each other. Should a link between two points exist the multimeter test prods emit a sound. Consequently, when a cable and its corresponding output are being touched simultaneously by the test prods a sound should be emitted whereas silence should be kept if different outputs are being touched. It can be deduced from the test results that everything is rightly connected which allows to introduce the sensor functionality testing. To conduct the later a supply source and an oscilloscope are necessary. Ground and supply cables which are the black and the red one lead to the supply source. Due to the fact that the connection pin used later on to unite the sensors with the software has a capacity of maximal 5 V, for all sensors the supply source is being tuned to 5 V. The oscilloscope connects to the output voltage in order to measure the tension which runs through the sensor's installation and displays the received signal values. To do so, a reference cable is connected additionally from the oscilloscope to the ground pin. A simplified schematic drawing of the installation is given in Figure 24.

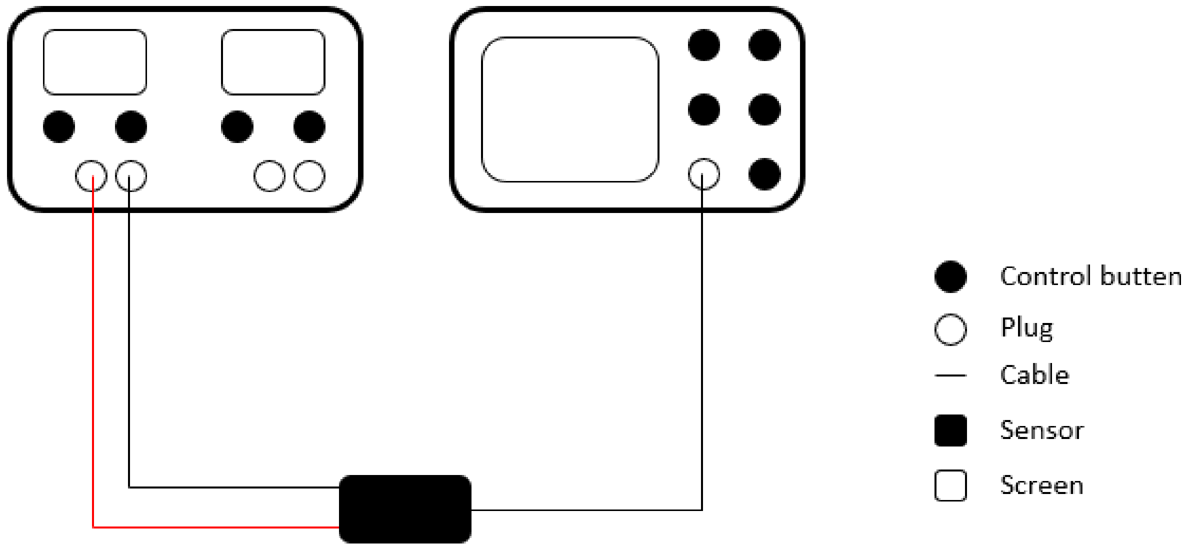

Figure 24 Schematic drawing of the installation – left: supply source, right: oscilloscope

First, the temperature sensor is tried. After having connected all outputs like explained above 23°C are indicated which corresponds approximately the actual temperature of the laboratory room without any important offset. Second in testing is the acceleration sensor. Of its six outputs two are ground pins but only one of them is needed since both are connected to each other. The fact that there is a second one originates more out of symmetry and stability reasons. Another of the outputs measures the temperature (blue cable) which will not be considered any further due to the fact that we already have a separate temperature sensor. The green cable connects to the y-axis output pin and the brown one to the x-axis output pin. A square wave signal is displayed on the oscilloscope. When the sensor is moved, the period width of the wave stays constant while the positive signal width keeps changing according to the movement. This correspond to the sensor's description in the datasheet for which its right functionality can be confirmed. Similarly, the compass sensor is connected and tested on third place. A square wave signal is displayed, changing according to the sensor's movement. In difference to the acceleration sensor the constant width is the low signal width – the signal going down to zero between each measured one – which again matches the datasheets description, confirming its functionality. Last in testing is the pressure sensor. It has six outputs from which only three are of need here: ground, supply and outgoing voltage. The residual three are additional to give the possibility to incorporate the sensor into a bigger circuit if needed. Since the sensor is differential it measures the difference between the reference side and the actual pressure. Should both be equal, an output voltage between 0.088 V and 0.313 V should be displayed. While testing the sensor 165.58 mV which equals 0.16558 V is indicated. This offset corresponds the given range of the datasheet and has to be subtracted from the value obtained by the sensor in the software later on before any conversion or calculation takes place. In order to directly get the absolute pression it is recommended to set the reference side to vacuum. Should this not be possible, the obtained pressure is relative since the reference would be the environment's pressure which has to be subtracted from the measured value in order to get the absolute pressure. Keeping the reference opening shut and blowing air through the other one results in amplitude variations pictured on the oscilloscope and indicating on this way that the sensor is working.

7. Programming the software and the visualization panel

Once all the sensors are tested and their functionality has been validated, the following step is to program a software in order to make the acquired data from the sensors accessible for users. Visualising the received data and processing the information to display them onto a panel is realized with the programming software LabView. Every object as well as the panel design have to be defined. LabView proposes several different visualization options. After trawling through the different design options for the front panel, the following style options have been encountered to be offered by LabView:

1. Modern
2. NXG Style
3. Silver
4. System
5. Classic

The Modern front panel option is the commonly employed one for creating user interfaces with controls and indicators. Its forms are mostly composed of simple, rectangular and clear lined shapes which integrate concavely into the panel background surface. If a front panel matching the LabView NXG style is required with controls and indicators adapting their form and design respective to the running VI platform, the NXG style is the most appropriate. Third listed is the Silver option. This style is above all applied on front panels whose principle task is to serve as user interfaces. Its controls and indicators have an elegant visual style with rounded edged and silver gleaming shapes. Adding the tools slightly emerging from the panel surface it leads to a smooth appearance. Next, the System style is proposed. It is especially adapted for working and programming with dialog boxes since the controls and indicators are arranged inside them and change according to the presently used standard dialog boxes. Last, the Classic style is useful if a colorless front panel is wished due to the fact that the basic colors are restricted to black and white. Also, the appearances of controls and indicators can easily be customized inside this style option [26].

According to the purpose of this project the Modern or the Silver style seem the most appropriate. Since both are fulfilling and are mainly dedicated to the user interface function it is above all a question of appearance respective to the choice which one is to employ. Due to its smooth appearance the Silver style has mostly been chosen. Further, in order to replicate as best as possible a general aviation instrument panel six gauges are arranged as in a general aviation instrument panel. The horizon and the rotation gauge are introduced as a placeholder to better match the replication even if they are not connected with any code. Additionally to the general aviation instrument panel, a section for the temperature sensor is introduced as well as various indicators and graphical indicators for every sensor in order to be able to follow the data of the sensor and its processing. Further, a control to start and one to stop the whole program are collocated next to the general aviation instrument panel and a second control section is added. The latter indicates through a green light if the corresponding sensor receives any data flow and is working while it simultaneously permits to stop the data flow of arbitrary sensors and by this to stop displaying their processed data on the front panel. Figure 25 and Figure 26 depict the final design of the front panel while Figure 27, Figure 28 and Figure 29 give insight into the code which runs behind the graphical surface. In Chapter 8 the block diagram of each sensor is shown separately in one figure in order to better retrace the coding. It has to be mentioned that the formula nodes used in the coding contain the equations necessary to complete the conversions from the acquired signals to the required values and to transform the values into different units as described in Chapter 3 and Chapter 5.

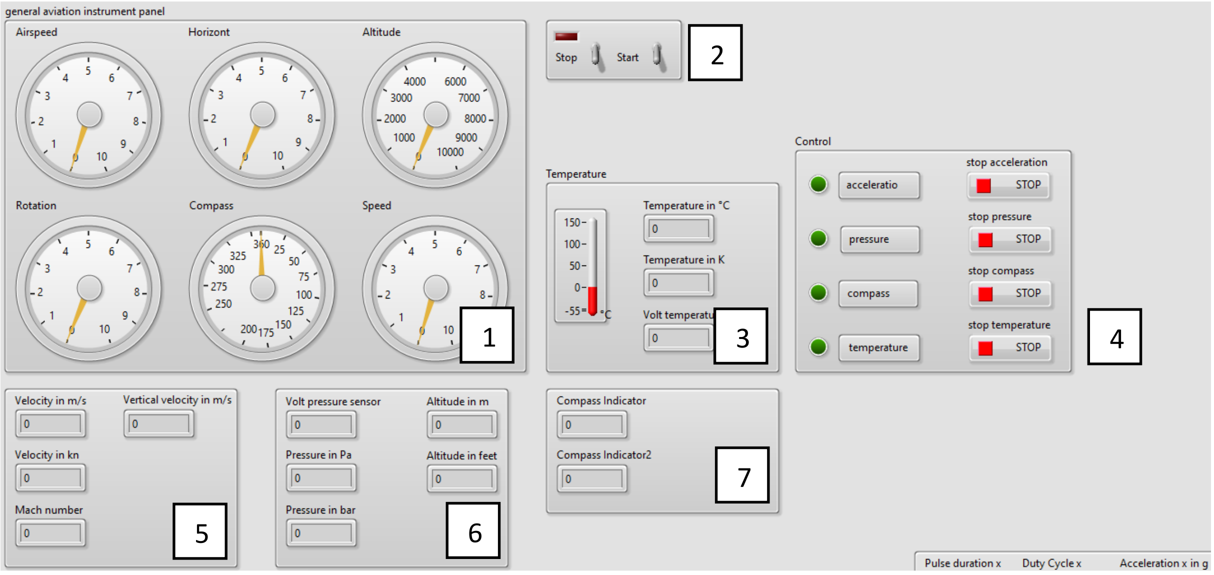

Figure 25 View of the designed front panel (first part) – 1. General aviation instrument panel, 2. Control button, 3. Temperature indicator box, 4. Control indicator box, 5. Velocity indicator box, 6. Pressure and altitude indicator box, 7. Compass indicator box

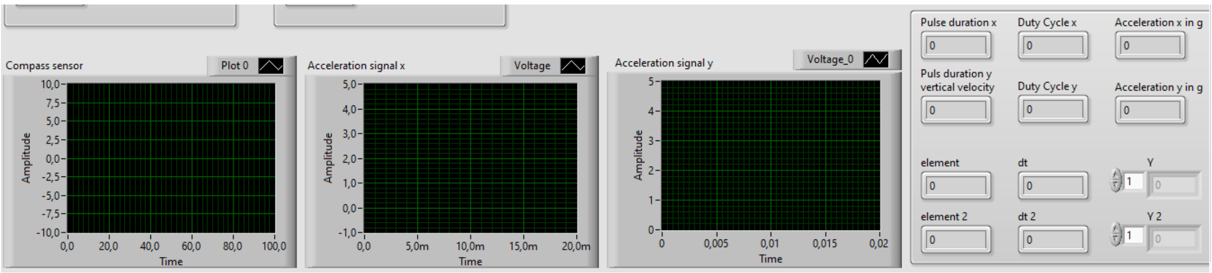

*Figure 26 View of the designed f*ront panel (second part) – from left to right: compass graphical indicator, acceleration graphical indicator, vertical acceleration graphical indicator, acceleration indicator box

Followingly, the used items and objects in the front panel will shortly be introduced according to where they are sorted inside the control palette. The Modern and the Silver programming library have been employed. Respective to the Silver programming library every introduced gauge and numeric indicator as well as the thermometer are to be found in the sub library Numeric. The stop buttons and the round LED originate from the sub library Boolean while all the rounded boxes belong to the sub library Decorations. Regarding the Modern programming library, both the vertical toggle switchs and the square LED correspond to the sub library Boolean. Every employed waveform graph can be found in the sub library Graph.

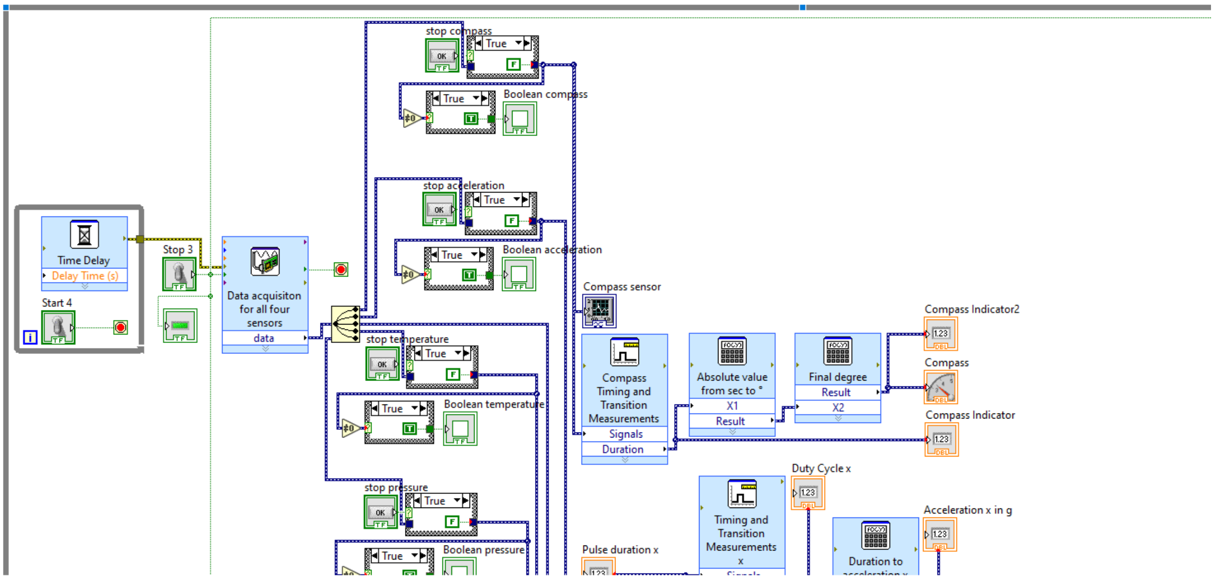

Figure 27 View of the designed block diagram panel (first part)

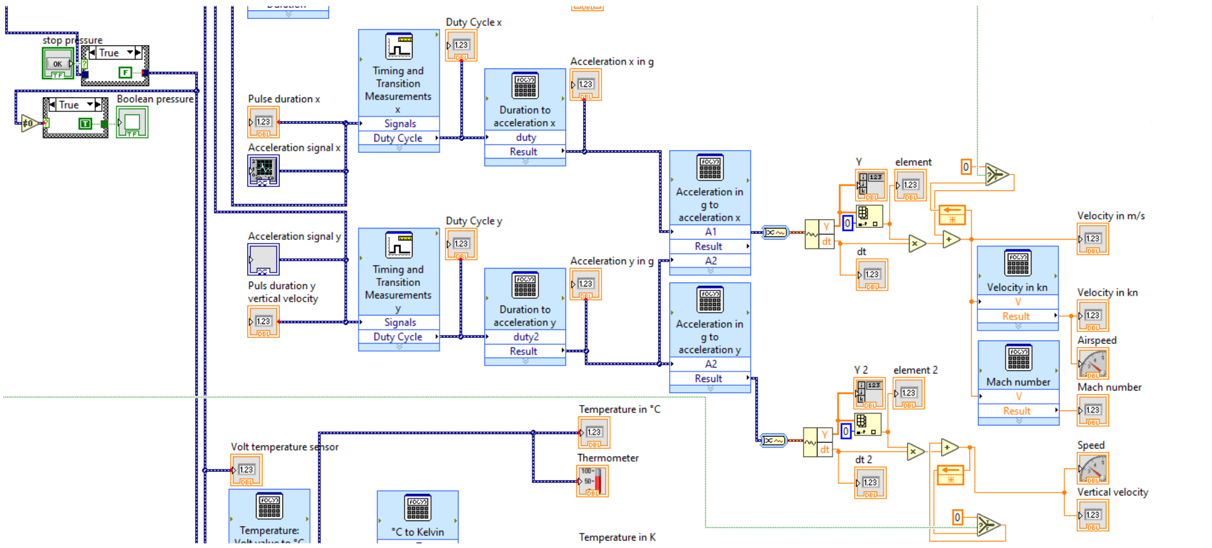

Figure 28 View of the designed Block diagram panel (second part)

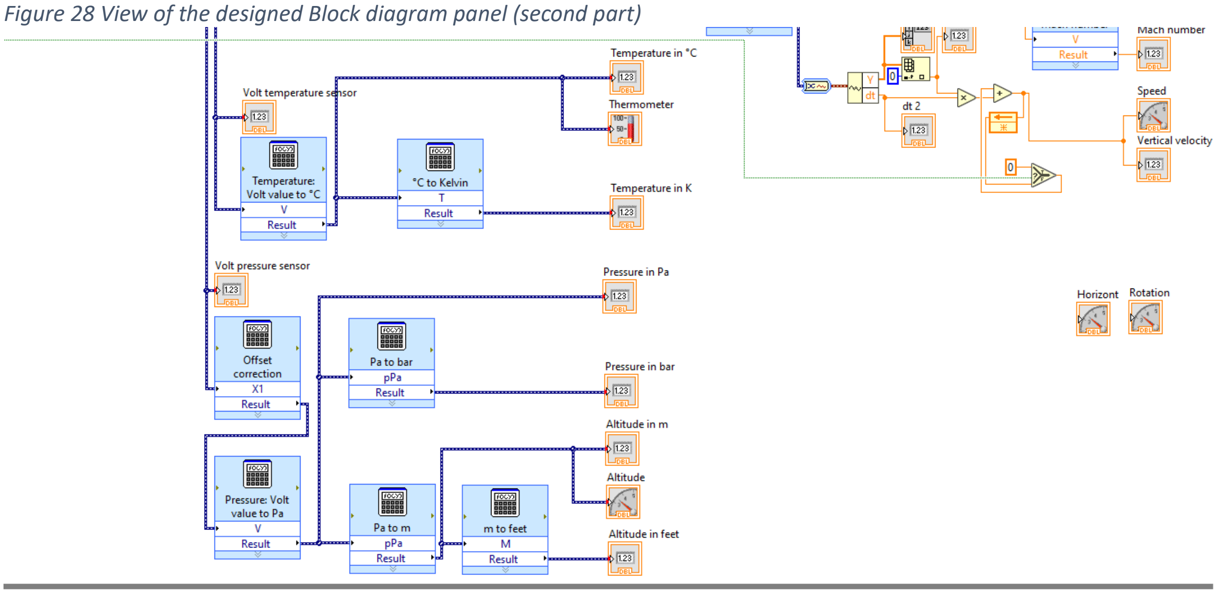

Figure 29 View of the designed Block diagram panel (third part)

Now follows an explanation of the block diagram. First, in order to acquire and gather the data a Data Acquisition (DAQ) block is introduced. A vertical toggle switch is added to enable to stop the program and a square LED as a Boolean indicator is connected to the stop button indicating the effect of the switch: red light means the program is deactivated, an extinguished LED refers to a running program. In front of the DAQ another toggle switch is collocated, placed inside a while loop and dedicated to starting the program if switched. Consequently, even if the arrow shaped run button of the programming platform is pressed, the program is only activated after additionally switching the start toggle switch. In order to inhibit the constant repetition of the loop which would consume energy, a time delay block is placed inside the loop structure.
The DAQ collects the information of all four sensors. In order to not intermingle the data, each sensor output pin is connected to a separate channel as indicated in Table 9. The software has a set sampling rate of 2000 Hz. This frequency has been decided sufficient due to the fact that temperature values and the orientation of the system represented in the compass as well as the pressure are not changing at high rates especially not in the given testing environment. Further, regarding the acceleration sensor, only low vibration is required within the framework of this thesis. The software settings are listed in Table 8. Since the frequency is 2000 Hz and within this margin 400 samples are to be read, every 200 ms there is a short stop in order to read the actual value and display it on the panel. This procedure is repeated continuously due to the chosen acquisition mode as long as the program is running.

Table 8 Software settings

Software settings	Values
Acquisition mode	Continuous samples
Samples to read	400
Frequency	2000 Hz
Signal input range	± 5 V

Table 9 Acquisition card connections

Voltage output	Port	Voltage/CH+	Voltage/CH-
Voltage_compass	a0	CB-68LP/68	CB-68LP/34
Voltage_acceleration	a1	CB-68LP/33	CB-68LP/66
Voltage_acceleration_vertical	a2	CB-68LP/65	CB-68LP/31
Voltage_temperature	a3	CB-68LP/30	CB-68LP/63
Voltage_pressure	a4	CB-68LP/28	CB-68LP/61

Next, the data is lead to different blocks dedicated to process and transform the data to the required values. For this the cable coming from the DAQ leads to a split signal tool which ensures that the data of each sensor flows through a separate cable. A case structure related to a Boolean stop button is attached to each cable permitting to stop the data flow of each sensor separately if need be. If the button is pressed, the signal is returning true and the data is not led out of the structure whereas in the case false the button has not been pressed and the data flows through the structure. A sidelined cable leading to a second case structure and related to a Boolean round LED rends possible to indicate if the sensor cable has been cut off or not. Should the entering data equal zero, the case is false and the LED stays extinguished. Should data enter though, the LED lights up in green due to the case true representing a data flow. Each button and switch need to be put into the mode *switch when pressed* under the register *properties* in order to accomplish the described functions.
Subsequently, the cables lead to graph indicators or numeric indicators in order to depict the received voltage value or pulse duration and render possible a first controlling of the data.

The cables of the compass and of the acceleration sensor adjacently connect to timing and transition measurements blocks. Those blocks transform the incoming signal into a duration value in case of the compass sensor and into a duty cycle value in case of the acceleration sensor. Two following formula nodes convert the duration value into degrees (Formula 27) whose result is presented in a numeric indicator and a gauge indicator. Additionally, a numeric indicator is connected to the timing and transition measurements block allowing to better follow and check the data conversion.
For the acceleration sensor, the vertical and horizontal axis have separated paths. Each duty cycle value is depicted through a numeric indicator and converted to the corresponding acceleration value in g through a formula node (Formula 16). Their results again are shown in numeric indicators before being led to further formula nodes which transform the acceleration value from the unit g to the unit meter per seconds (Formula 17). In order to obtain the vertical velocity as well as the total velocity, the path of the vertical axis leads to a separate formula node and to the horizontal axis formula node where both values are being combined (Formula 8). After this the values are integrated and expressed in numeric indicators as well as in a gauge in the case of the vertical speed. The integration is conducted as following. A configure converts the dynamic data into a single waveform which components dt and Y are acquired through the following block. In order to render the array properties Y and the dt visible two indicators are added. The Y's are led to the index array function which returns the element or subarray of n-dimension array at index. It resizes automatically to display index inputs for each dimension in the array for which reason the index is put to zero. Each single Y is now multiplied with the value dt and successively summed up with help of a feedback node. In summary this procedure represents cutting the surface under the wave in small rectangles and adding them one to another in order to reconstruct the surface. The lower the dt value the more the reconstructed result is converging towards the real one. In order to ensure all values are set to zero if the general stop switch is activated, a select function is integrated. Without this function the stop and restart of the program would not erase the sum but save the result obtained before the stop and keep adding the new data after reinitializing the program. The total velocity is additionally converted into the unit kn (Formula 18) and into the MA number (Formula 19) through different formula nodes whose results can be seen in numeric indicators and in the case of the first also in a gauge.
Both the temperature sensor and the pressure sensor cable directly lead to formula nodes due to the fact that their voltage value is proportional to the required values for which no timing and transition measurements block is necessary. The temperature sensor formula node covert the voltage value into a Celsius degree value (Formula 13) which is displayed on a thermometer and a numeric indicator. Further, the new value is translated to Kelvin through another formula node (Formula 14) whose result again leads to a numeric indicator.
The pressure sensor cable first connects to a formula node dedicated to correct the existing offset before joining a formula node which transfers the voltage value into Pa (Formula 22). The result is shown in a numeric indicator and converted into bar (Formula 23) and meters (Formula 25) through further formula nodes. The first is indicated in a numeric indicator the latter in both a numeric and a gauge indicator. Also, the value in meter is calculated to feet through a last formula node (Formula 26) which depicts its result in a numeric indicator.

8. Testing the software's functionality

In order to connect the sensors to the software and ensure the right functionality of the whole system, there are three steps to be followed. First, every channel of the software has to be tested separately by introducing an artificial signal to it. Next, one sensor at a time is connected to the software in order to prove its functionality while combined with the program. Last, all the sensors are being linked at the same time and the interaction of the whole hard- and software is being verified.

8.1. Testing of the software functionality by synthetic signals

As mentioned, each channel is tested separately with an artificial controlled signal generated with the help of a supply source and an oscilloscope. By this every acquisition channel can be validated. In order to provide a signal as similar to a real signal as possible some frame conditions have to be taken into account. The most important correlation to be aware of is the one between the signal frequency and the sampling rate. To not obtain a false signal the sampling rate has to be high enough and needs to be concerted to the frequency. A useful tool for doing so is the Nyquist-Shannon theorem which says that a signal can be reconstructed correctly by equidistant samplings if the sampling rate's value is at least twice as high as the maximal frequency of the signal (Formula 28).

$$f_{sr} \geq 2 \cdot f_{max} \tag{28}$$

The software has a set sampling rate of 2000 Hz. Consequently, the artificial signal frequency should not exceed 1000 Hz. To ensure an accurate emulation of the signal it has been decided to acquire at least 10 samples per cycle for which the upper frequency limit is 200 Hz.
Respective to how to connect the sensors to the acquisition card, a different port is assigned to each sensor output. The corresponding way to connect the wires can be looked up under the register Connection Diagram of the DAQ Assistant of LabView. Table 9 concentrate the connection information according to the acquisition card and the ports respective to the corresponding sensor output. All cables leading to the artificial signal system have to be introduced the same way.
The set variables for the artificial signal can be extracted from Table 10. If the signal wave form displayed on the software front panel as well as the amplitude and the maximum and minimum correspond to the settings it proves the right functionality of the channel itself resulting from a properly working connection between hard- and software. In order to ensure the functionality of the software or rather in order to examine the processing of the signals and their transformation into the required values, the displayed information on the panel have to coincided with the synthetical inputs and the data of the data sheets.

Table 10 Settings for the synthetic signals

	Compass	Temperature	Pressure	Acceleration
Amplitude (in V)	6	4	1	6
Offset (in V)	0	0	0	0
Maximum and Minimum (in V)	± 3	± 2	± 1.5	± 3
Frequency (in Hz)	20	20	20	20
Signal form	Rectangle wave-form	Sine wave-form	Sine wave-form	Rectangle wave-form

First, the compass is connected to the software and the result is displayed onto the panel as in

Figure 30 Compass panel – synthetic signal. The diagram displays a rectangle wave form with an amplitude and a maximum and minimum just as defined in the settings. This means the channel connection works appropriately. Next, according to the data sheet and the settings 250 degree are expected. Indeed, the value 0,025 is shown in the Compass Indicator displaying the measured pulse duration while 250 is indicated in the Compass Indicator2 representing 250 degrees. On the gauge the same value is visible proving that all three indicators are correctly related to each other. Conclusively the software processes the information as wished to.

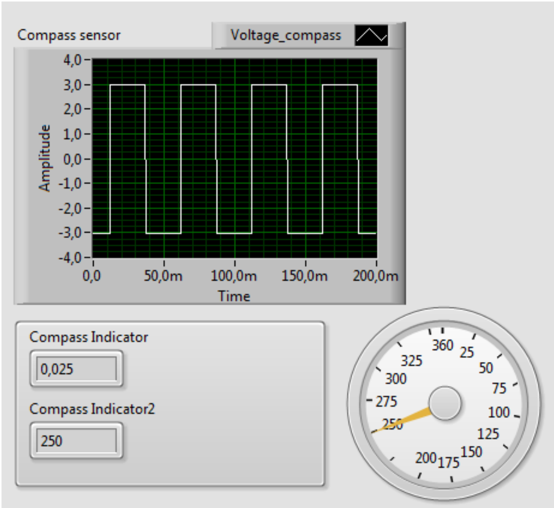

Figure 30 Compass panel – synthetic signal

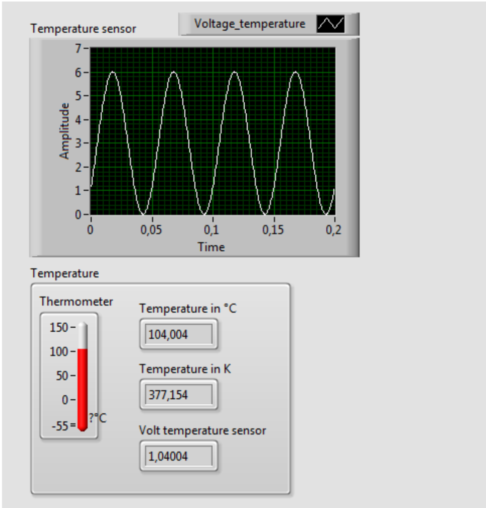

Figure 31 Temperature panel – synthetic signal

Figure 31 pictures the result of the second test in which a synthetic signal is connected to the temperature channel. The wave form as well as the amplitude and the maximum and minimum visible in the graph correspond the settings from which a correct connection through the channel can be deduced. Also, it is visible that the thermometer displays the same value as the temperature indicator in Celsius degree and that the one in Kelvin degree is being correctly transferred. According to the data sheet the input of the signal value which is indicated as 1,04054 V is being correctly transformed into a temperature value involving the right functionality of the software processing.

Third, the pressure channel test is conducted (Figure 32). Again, the wave form, the amplitude and the maximum and minimum are as expected respective to the settings. The channel connection is working properly. As to the software processing the conversions between the different altitude units and pressure units are correct. Further, the pressure altitude equation is rightly employed since the relation between the pressure value and the altitude value correlates. The gauge indicates zero due to the fact that the negative value exceeds its range capacities.

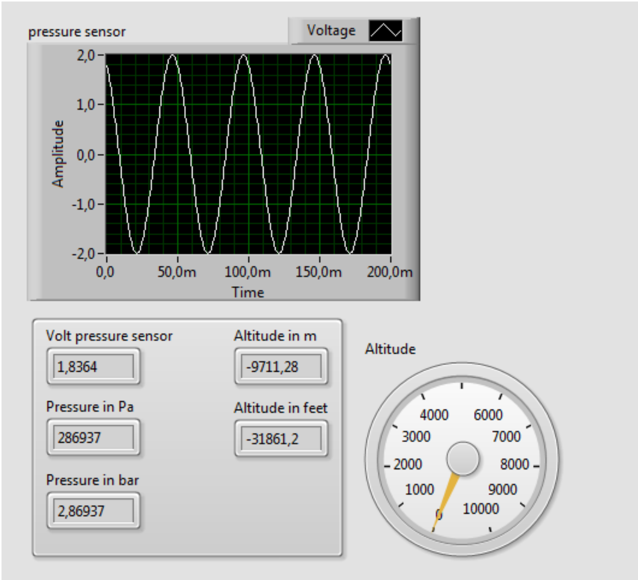

Figure 32 Pressure panel – synthetic signal

The acceleration test is executed fourth. Regarding the acceleration sensor is a dual axis sensor two tests have to be conducted separately, one for each axis. The test results of the channel dedicated to the vertical axis can be seen in Figure 34 whereas Figure 33 depicts the results for the other channel. As in all tests before the channel connection is proven correct for both axes considering the displayed wave form, amplitude and maximum and minimum match the settings. The velocity in meter per seconds or in knots as well as the Mach number cannot be calculated due to the fact that both the sensor inputs are needed at the same time. Thus, it is correct that the indicators reveal the value zero. Interestingly even though only one channel is connected at the time the free channel still receives a signal for which reason both indicators show a value. This is an evidence to the fact that there is a resonance between the channels. After testing the acquisition card, it can be noticed the all the channels have a resonance and influence each other. This will lead to false signals and values as soon as more than one sensor is being connected. Consequently, the resonance should be eliminated before connecting all the sensors.

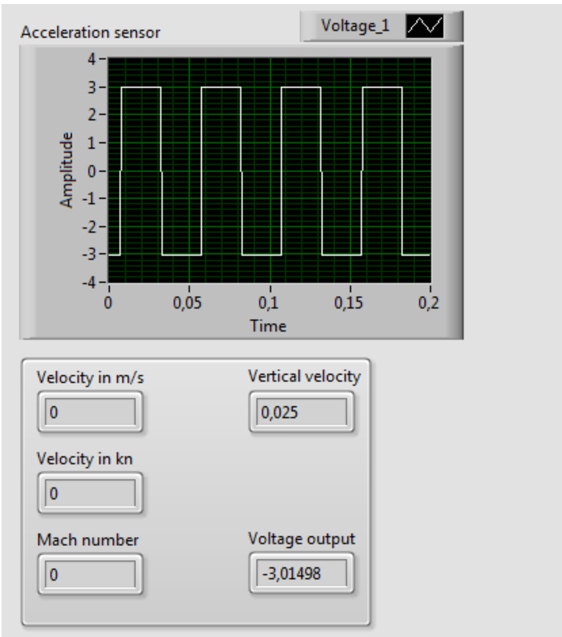

Figure 33 Acceleration panel – synthetical signal

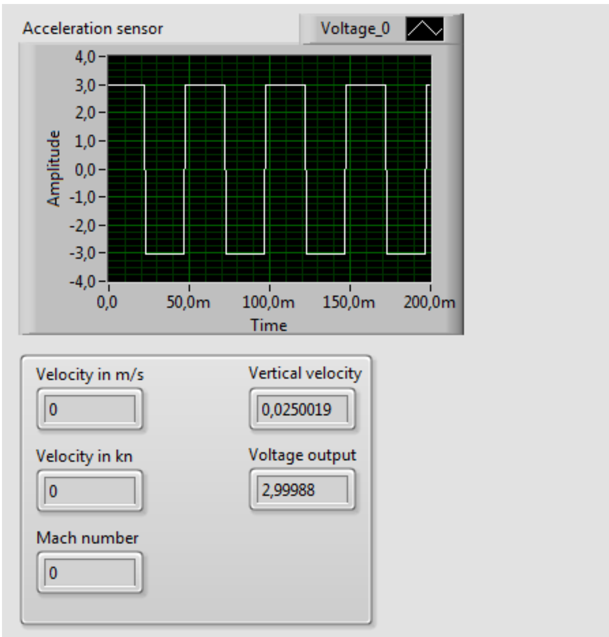

Figure 34 Vertical acceleration panel – synthetical signal

8.2. Testing of the software functionality by connecting sensors

After verifying the functionality of the software and of the channels with the help of a synthetic signal the sensors are being connected one by one to the corresponding channel and the outputs visualized on the panel are being surveyed. The sensors are connected to an alimentation source dispensing 5 Volt and to the acquisition card.
First, the compass sensor is being tested. While moving it in different directions, the pulse width differ and the indicators change their value accordingly. Also, the gauge cursor moves pointing to the same value the Compass Indicator2 displays. Figure 35 is an example for a wide pulse width resulting from orientating the sensor towards 340 degrees whereas in Figure 36 the sensor is tilted towards 100 degrees which leads to a small pulse width corresponding the explanations of the data sheet. The block diagram is shown in Figure 37.

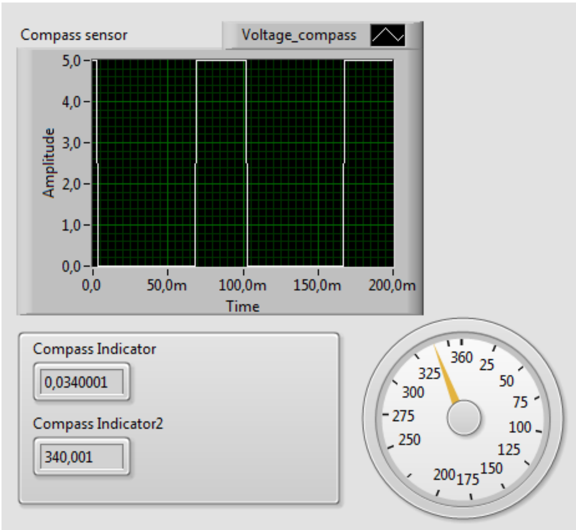

Figure 35 Compass panel – slow sensor signal

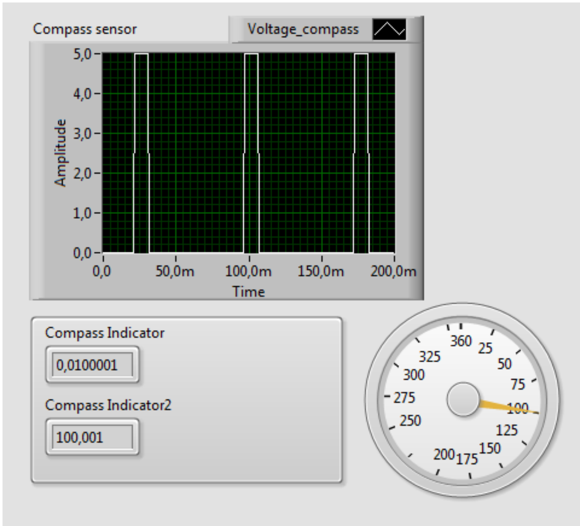

Figure 36 Compass panel – fast sensor signal

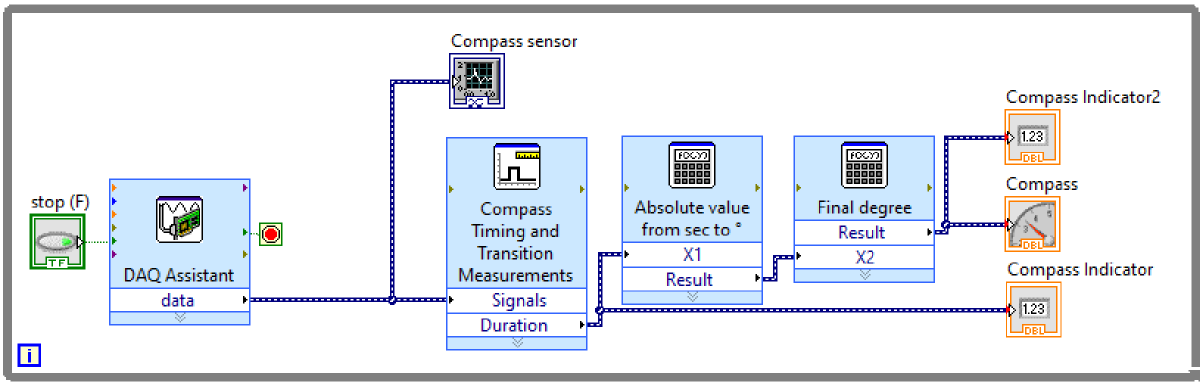

Figure 37 Compass – block diagram

Next, the temperature sensor is connected and verified. The laboratory room temperature is not exactly known but estimated to amount approximatively 20 degrees. For previous reason a similar value is expected to be displayed on the panel if the sensor only contacts the environments air. However, the panel thermometer as well as the temperature indicator in Celsius degree depicts 25 degrees which is a bit higher than the expected value but correspond to the voltage amplitude measured by the sensor. The conversion to Kelvin is made correctly. In order to calibrate the sensor, the room temperature is needed to be known to subsequently calculate the existing offset and include a correction in the block diagram conversions. A complete calibration would be too laborious and impossible to accomplish in the given conditions due to following reasons. The measured voltage amplitude is directly proportional to the present temperature (Figure 38, 1). Should there be an offset the present temperature would correspond another voltage value (Figure 38, 2). By knowing the exact room temperature of the laboratory and by comparing it to the indicated temperature on the panel the offset can be determined and corresponding corrections can be introduced. Nevertheless, this offset would only be the one for the actual temperature while for another temperature the offset could be different. Measuring only one temperature is not enough to identify the offset curve. It could be a linear curve but then again, the gradient would remain unknown (Figure 38, 3) or it could even have a non-linear curse. Due to explained coherencies a complete calibration can only be accomplished by measuring various temperatures and comparing them to the present ones in order to be able to evaluate the offset curve. Since the temperature of the laboratory cannot be altered enough times to achieve an adequate data basis no calibration can be conducted.

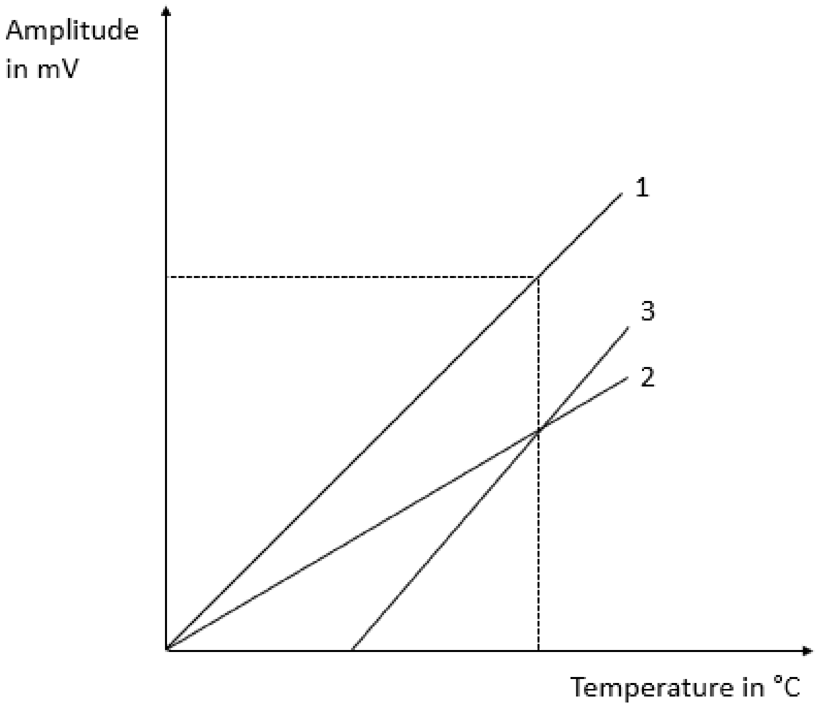

Figure 38 Offset – explained using the example of the temperature

When installing the sensor near a heat source a rising temperature value can be observed in all four indicators, including the thermometer, and all values are coinciding to each other. Figure 39 gives an insight into the front panel during the temperature sensor testing. A picture of the block diagram used in order to acquire and process the incoming signal is shown in Figure 40.

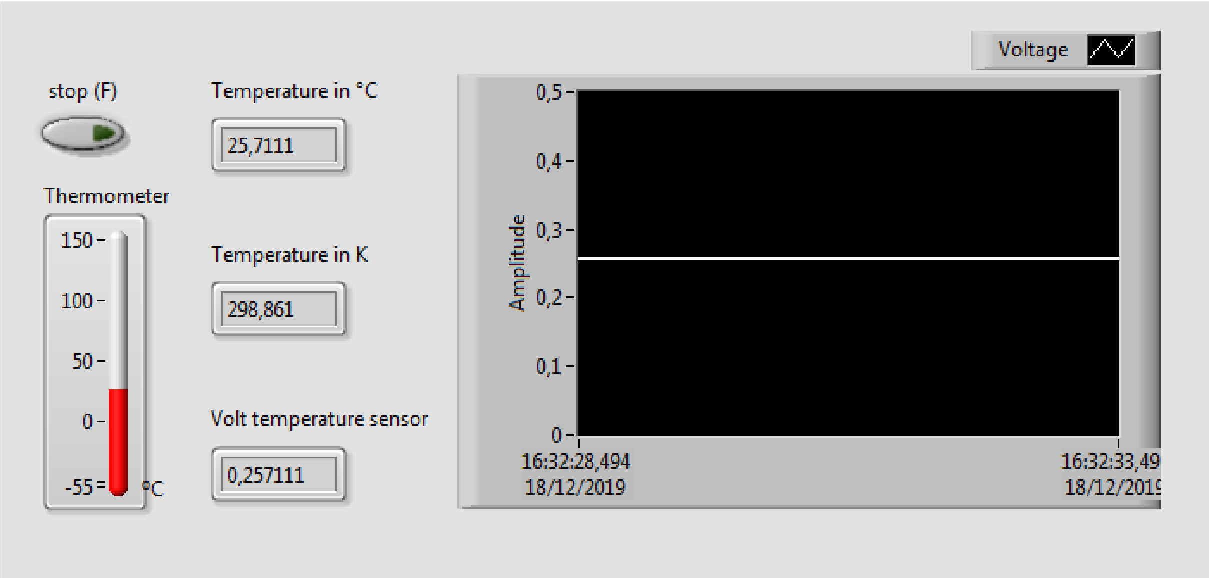

Figure 39 Temperature panel – room temperature

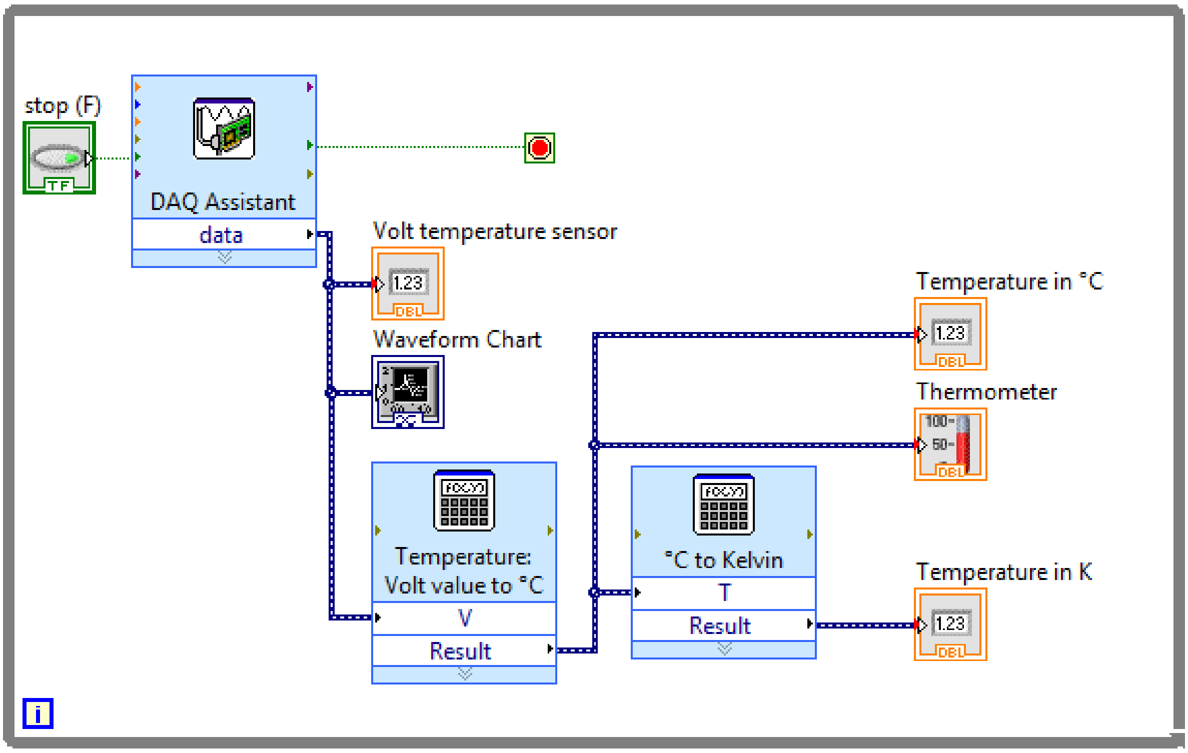

Figure 40 Temperature – block diagram

Third, the pressure sensor is being verified. Figure 41 shows a snap-shot taken during the testing. As expected, after proving the functionality of both channel and software processing the conversions between the different altitude units and pressure units are correct as well as their relation towards each other resulting from the employment of the pressure altitude equation. Further, the gauge indicates the same value as the altitude indicator in meters. According to the data sheet the lowest voltage value able to be measured is 0,2. Consequently 0,2 V corresponds 0 bar. The snap-shot depicts 0,19 V, rounded 0,2 V, or 0 bar though the laboratory room pressure obviously cannot amount this pressure. Nevertheless, the indicated values are correct and the sensor is working properly. The reason lies in the sensor working method. Since it does not directly measure the present pressure of the environment but the reference to the vacuum side of the sensor if both entrances are exposed to the same pressure as it is the case during which the snap-shot has be taken, the result is 0 bar. By closing one entrance and blowing air through the other one the indicators change correspondingly. The graphic indicator depicts a signal overridden by noise. In Figure 42 the block diagram standing behind the user interface panel is be shown. During the first testing respective to the sensor functionality an offset of 0.16558 V had been detected. Since the offset calibration directly through the software often proves to be more precise, block diagrams dedicated to this function are included and an offset of 0,19 is been ascertained and newly set in the correction block.

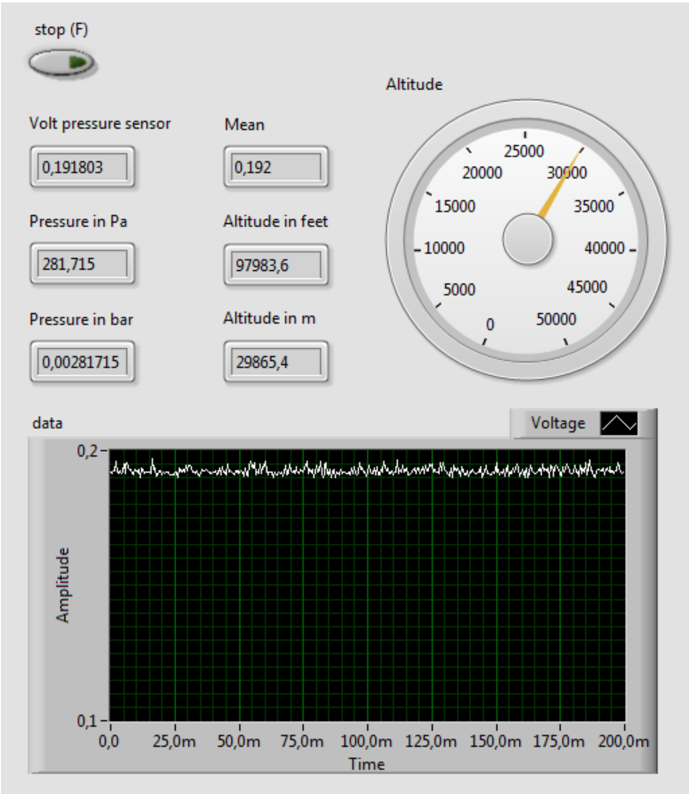

Figure 41 Pressure panel – sensor signal

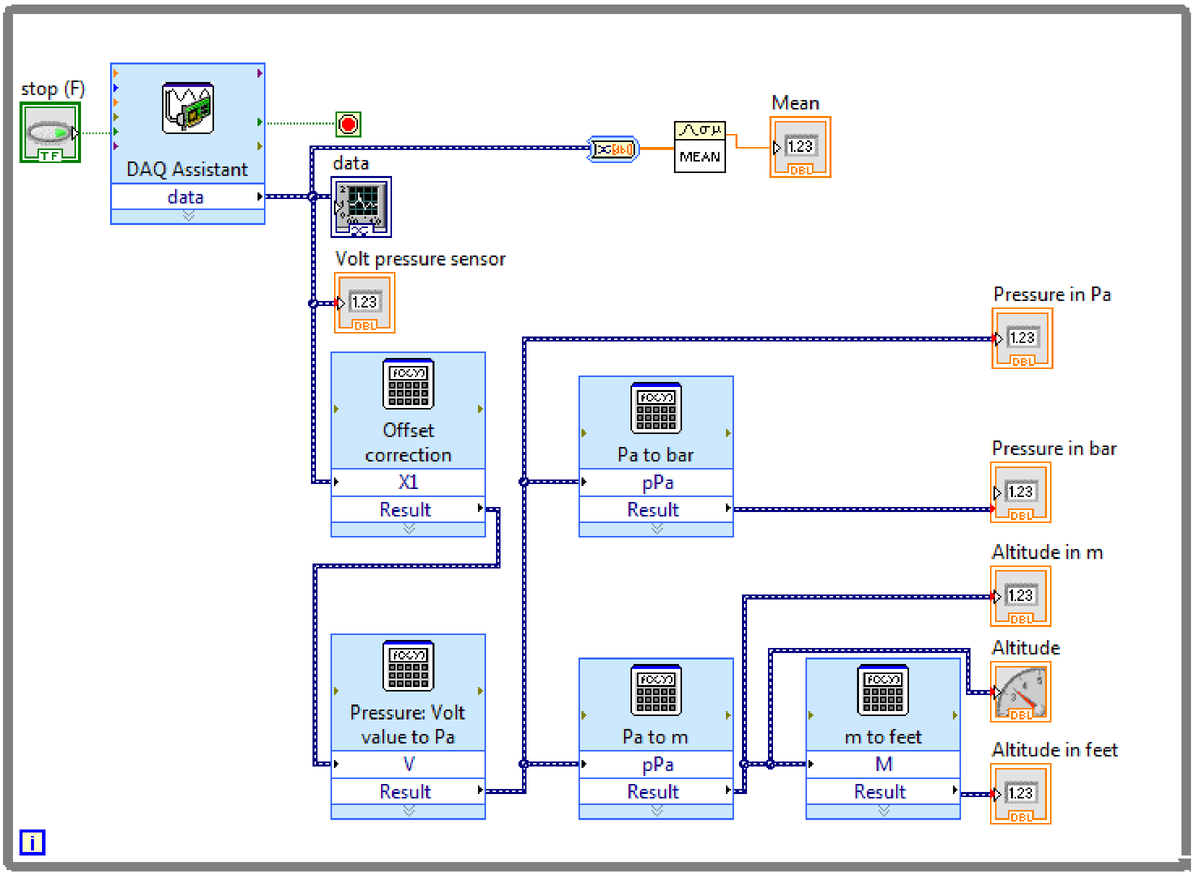

Figure 42 Pressure – block diagram

Figure 43 pictures the test respective to the acceleration sensor. Both channels are being connected simultaneously. Consequently, the velocity in meter per seconds or in knots as well as the Mach number should be able to be calculated due to the fact that both sensor inputs are available. The outputs of the different indicators change when the sensor is moved to provoke an acceleration and the relations between the different indicators are correct from which a correct conversion and translation between the different units and the values can be deduced. Congenial to the sensor working modus explained in the data sheet, the graphic indicator shows a rectangle wave signal. Figure 44 gives an insight into the block diagram of the acceleration sensor.

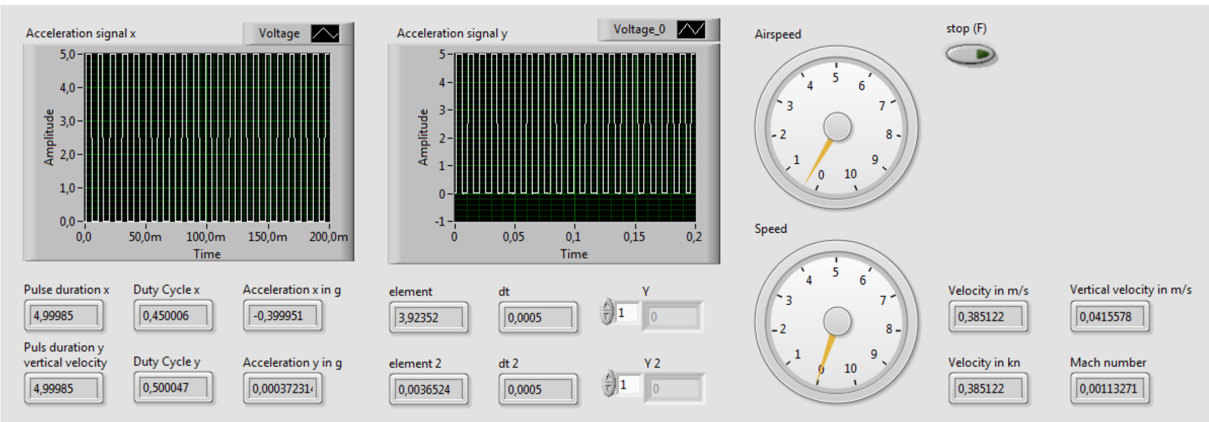

Figure 43 Acceleration panel – sensor signal

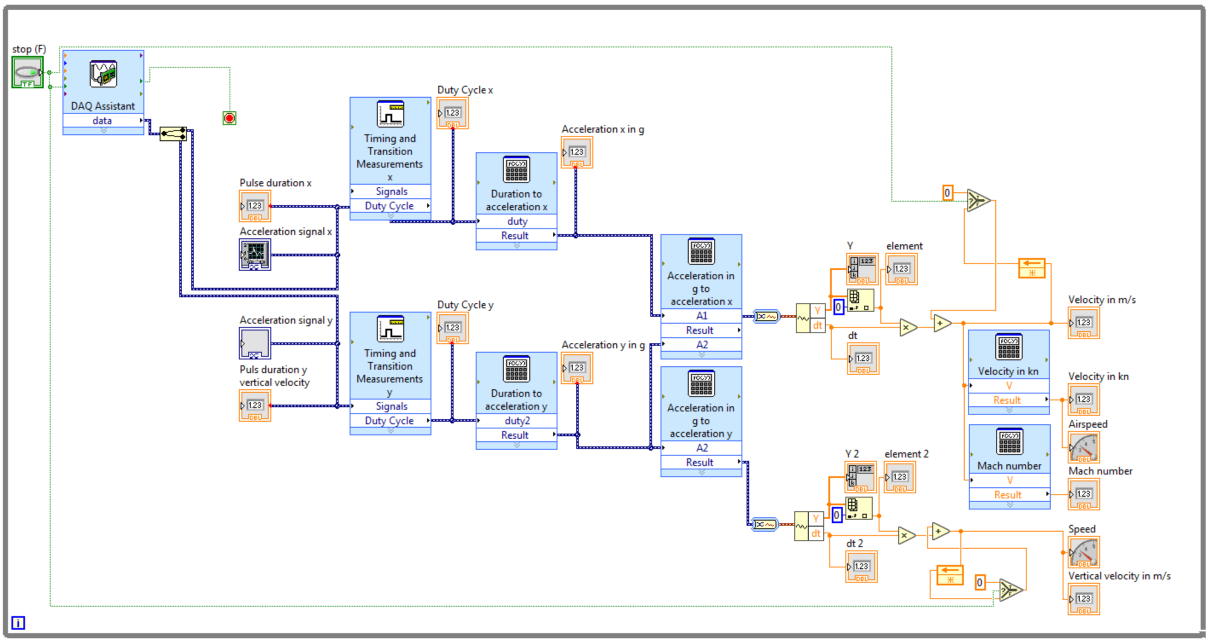

Figure 44 Acceleration panel – block diagram

8.3. Testing of the whole system

Finally, all the sensors are being connected to the software and the final test is being conducted with the aim to prove the functionality of the interaction of the whole hard- and software. In order to facilitate the connection of all the sensors and to use as few cables as possible which helps avoiding to mix the cables up and to confuse the connections, the ground and supply pins of the acquisition card are employed instead of the previously used supply source. In Table 11 the signification of each acquisition card pin is listed. The sensors are connected to the acquisition card as indicated previously in Table 9. Each ground cable is further linked to the nearest ground pin of the card through an extra cable (for example pin 67 is the nearest ground pin to pin 34) and all supply cables lead to the same supply pin, which is pin 14 in this case.

68 ACH0	61 ACH12	15 DGND	08 +5V	01 FREQ_OUT
34 ACH8	27 AIGND	49 DIO2	42 GPCTR1_SRC	35 DGND
67 AIGND	60 ACH5	16 DIO6	9 DGND	2 GPCTR0_OUT
33 ACH1	26 ACH13	50 DGND	43 CONVERT	36 DGND
66 ACH9	59 AIGND	17 DIO1	10 TRIG2	3 GPCTR0_GATE
32 AIGND	25 ACH6	51 DIO5	44 DGND	37 GPCTR0_SRC
65 ACH2	58 ACH14	18 DGND	11 TRIG1	4 DGND
31 ACH10	24 AIGND	52 DIO0	45 EXTSTROBE	38 STARTSCAN
64 AIGND	57 ACH7	19 DIO4	12 DGND	5 WFTRIG
30 ACH3	23 ACH15	53 DGND	46 SCANCLK	39 DGND
63 ACH11	56 AIGND	20 RESERVED	13 DGND	6 UPDATE
29 AIGND	22 DAC0OUT	54 AOGND	47 DIO3	40 GPCTR1_OUT
62 AISENSE	55 AOGND	NA NA	14 +5V	7 DGND
28 ACH4	21 DAC1OUT	NA NA	48 DIO7	41 GPCTR1_GATE

Table 11 Acquisition card – dark grey: ground pin, light grey: supply pin

As expected, after having already verified the right functionality of every single sensor and channel, the interaction works properly. Every transformation of data appears as it should and the numeric and graphic indicators, the gauges as well as the thermometer depict corresponding values. Snapshots taken during the testing are shown in Figure 45 and Figure 46. There are no noticeable problems or abnormalities.

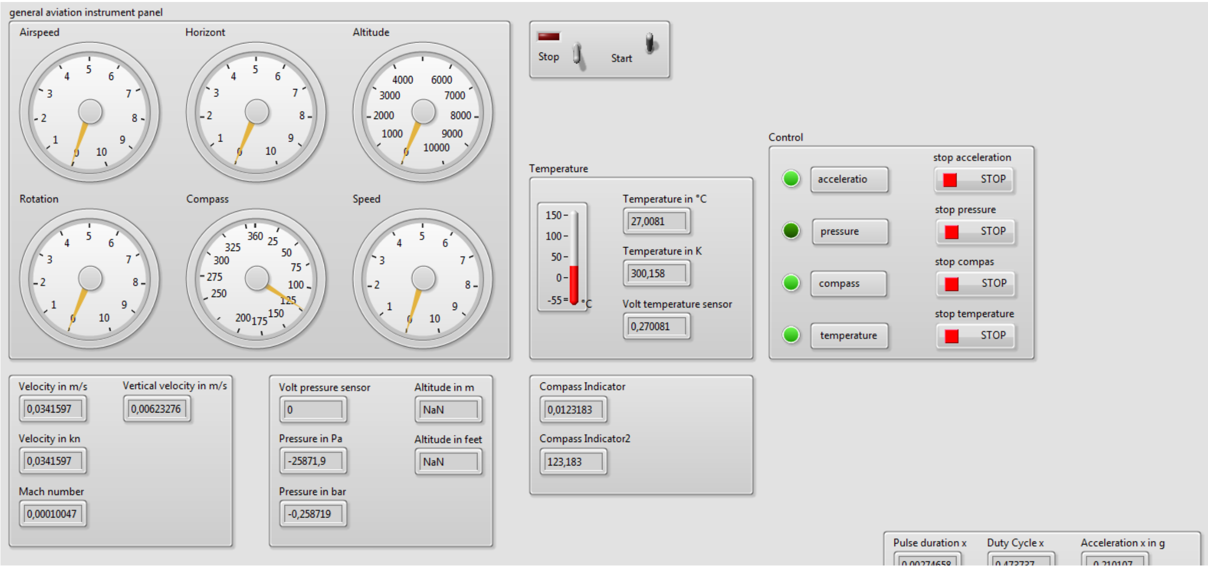

Figure 45 Front panel (1) – final testing

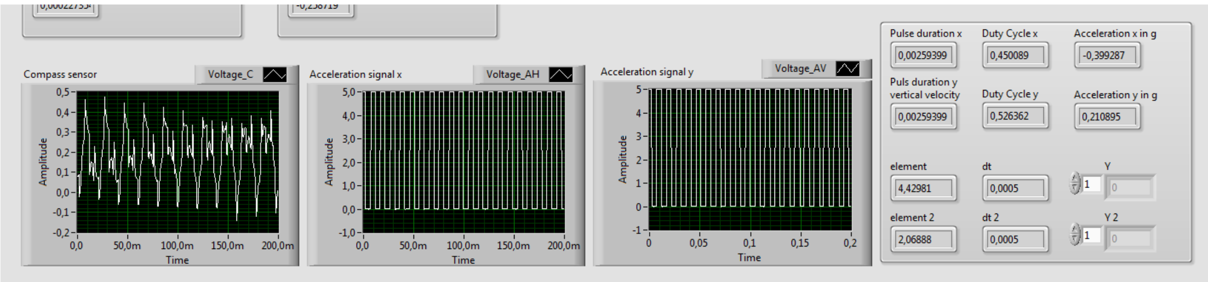

Figure 46 Front panel (2) – final testing

9. Summary and outlook

In this thesis the programming platform LabView has been used in order to connect four different sensors to the software and visualise their data on a graphical surface. Since the aim was to choose aeronautic related sensors, a temperature sensor, a pressure sensor, a compass sensor and an acceleration sensor have been chosen to copy as close as possible a general aviation instrument panel. The data of each sensor is successfully being processed and visualized through the acquisition system of National Instruments LabView. A virtual general aviation instrument panel has been created as far as possible with the given materials and under the given conditions.

As continuative steps different sensors of the same outcome type can be incorporated into the environment in order to verify if their connection to the system is realizable with only little changes which was one of the expectations set at the beginning.

Further, the general aviation instrument panel can be extended and completed in order to better represent the functionality of a real one. Especially the horizon and the rotation gauge which are missing in the simulation and only appears in this version as placeholder on the front panel can be programmed and added to the existing software.

In addition, the sensors can be attached to some testing object and be collocated in an adequate testing and simulation environment. This would permit to use and test the full capacity of the sensors measuring ranges. For example, cooling or heating chambers can be used in order to expose the temperature sensor to different temperatures and simulate an uprising of an airplane, knowing that the temperature cools down with increasing high. Also, the acceleration sensor can be replaced by a pitot tube in order to measure the velocity as it is usually measured in airplanes. This done a wind tunnel or a similar environment can be used in order to change the pressure and the velocity of flow and by this simulate a flying airplane.

Besides, in order to obtain more exact data about the surrounding environment an exact calibration needs to be conducted. Above all the temperature sensor has an offset which still is unknown and should be determined if a more realistic simulation is wished.

This practical session dedicated and created for students studying in the aeronautic field had further the educational aim to give the student the possibility to approach the principle of operation of instrumentation and data. Effectively the principles of converting analogue signals to digital data and visualize this data on a panel after acquiring, processing and converting it have become very clear. Thanks to the manageable and comprehensibly structured programming platform LabView laypersons quickly get an impression of the stages to pursue in order to process and visualize data on monitors or panels. It accentuates that in order to express data in an understandable way visualizing it on panels is helpful and capacitate the students to replicate and simulate panels of other machines in a similar way. The educational aim was met.

In order to consolidate the newly acquired ability students could as continuative steps transfer their knowledge onto other machinery panels and replicate those ones or change the design of the existing one. This would permit them to deepen their understanding of the software and to widen their horizon respective to the different functions and design options as well as to the large variety of tools LabView is offering.

8 References

[1] AERO EXPO. 2019. *barometrischer Drucksensor / Vdc / in mA / für Flugzeuge MLH Series* (2019). Retrieved October 17, 2019 from https://www.aeroexpo.online/de/prod/honeywell-safety-and-productivity-solutions/product-186046-37363.html.

[2] AliExpress. 2019. *LM35 Precision Centigrade Temperature Sensors* (2019). Retrieved January 6, 2020 from es.aliexpress.com/wholesale?catId=0&initiative_id=SB_20200106062727&SearchText=LM35+Precision+Centigrade+Temperature+Sensors.

[3] Inc. Analog Devices. 2009. *Small, Low Power, 3-Axis ±3 g Accelerometer ADXL335* (2009). Retrieved December 11, 2019 from https://www.sparkfun.com/datasheets/Components/SMD/adxl335.pdf.

[4] Analog Devices Inc. 2015. *Low Voltage Temperature Sensors*. *Data Sheet TMP35/TMP36/TMP37* (2015). Retrieved December 12, 2019 from https://www.analog.com/media/en/technical-documentation/data-sheets/TMP35_36_37.pdf.

[5] Astrid Lampert, Martin Schachtebeck, Rudolf Hankers, Kjell zum Berge. 2019. *Flugmeteorologie*. *Wetter, sein Einfluss auf die Luftfahrt und Messmethoden.* Institut für Flugführung. Technische Universität Braunschweig, Braunschweig.

[6] Christopher S. Baird. 2013. *Why does a magnetic compass point to the Geographic North Pole?* (2013). Retrieved December 28, 2019 from https://wtamu.edu/~cbaird/sq/2013/11/15/why-does-a-magnetic-compass-point-to-the-geographic-north-pole/.

[7] Clint Budd. 2016. *Heading 295 Magnetic.* (2016). Retrieved December 4, 2019 from https://www.flickr.com/photos/58827557@N06/29181693970.

[8] Denelson83. 2009. *Datei:Primary Flight Display.svg* (2009). Retrieved December 4, 2019 from https://de.wikipedia.org/wiki/Datei:Primary_Flight_Display.svg.

[9] Deutscher Wetterdienst. 2019. *ICAO-Standardatmosphäre (ISA)* (2019). Retrieved December 4, 2019 from https://www.dwd.de/DE/service/lexikon/begriffe/S/Standardatmosphaere_pdf.pdf?__blob=publicationFile&v=3.

[10] Edgar von Hinüber. 2002. *Inertiale Messsysteme mit faseroptischen Kreiseln für Fahrdynamik und Topologiedaten-Erfassung*. ENTWICKLUNG Fahrdynamik (2002). Retrieved December 11, 2019 from imar-navigation.de/downloads/papers/atz_6_2002_printoff_de.pdf.

[11] Freescale_Semiconductor_Inc., Ed. 2012. *Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated*. Data Sheet: Technical Data.

[12] Geoff McKay. 2010. *Six Pack – The Primary Flight Instruments* (2010). Retrieved November 6, 2019 from https://learntofly.ca/six-pack-primary-flight-instruments/.

[13] induux Wiki. 2019. *Sensoren* (2019). Retrieved October 16, 2019 from https://wiki.induux.de/Sensoren.

[14] Jens Friedrichs. 2017. *Airline Operation*. *Übung 2: Triebwerks-Crash-Kurs.* Institut für Flugantriebe und Strömungsmaschinen. Technische Universität Braunschweig, Braunschweig.

[15] José Luis Romeral Martínez. 2018. *PRÁCTICA 1: Sistemas de Instrumentación: Lab View. Aplicación: Lectura y procesado de señales analógicas.* Departament d'enginyeria electrònica. UPC BarcelonaTECH, Barcelona.

[16] Katharina Juschkat. 2019. *Sensor*. *Wie Sensoren funktionieren und wo sie eingesetzt werden* (2019). Retrieved October 16, 2019 from https://www.elektrotechnik.vogel.de/wie-sensoren-funktionieren-und-wo-sie-eingesetzt-werden-a-713477/.

[17] Krzysztof Tokarz. 2019. *Earth's magnetic field vector in three dimensions* (2019). Retrieved December 28, 2019 from https://www.researchgate.net/figure/Earths-magnetic-field-vector-in-three-dimensions_fig3_262176296.

[18] Maria Budweiser. 2011. *Die Barometrische Höhenformel*. *Vortrag von Maria Budweiser im Rahmen der "Übungen im Vortragen mit Demonstrationen - Physikalische Chemie", WS 11/12*. Didaktik der Chemie (2011). Retrieved November 4, 2019 from daten.didaktikchemie.uni-bayreuth.de/umat/hoehenformel_barometrisch/hoehenf_barometrisch.html.

[19] MercadoLibre. 2019. *cmps03 compass module brujla digital* (2019). Retrieved January 6, 2020 from https://listado.mercadolibre.com.mx/cmps03-compass-module-brujla-digital.

[20] Miguel Delgado. 2018. *Tutorial de LabView.* Departament d'enginyeria electrònica. UPC BarcelonaTECH, Barcelona.

[21] Mirko Ribow. 2009. *Ausbildungsseminar Klima und Wetter im WS 09/10*. *Druck und Temperaturschichtung in der Atmosphäre*.

[22] Modern Robotics Inc. 2016. *Modern Robotics Inc. Sensor Documentation* (2016). Retrieved December 11, 2019 from https://docplayer.net/26385945-Modern-robotics-inc-sensor-documentation.html.

[23] mSparks43. 2018. *Temperature above ISA tropopause* (2018). Retrieved December 28, 2019 from https://forums.x-plane.org/index.php?/forums/topic/157579-temperature-above-isa-tropopause/.

[24] National Instruments Corporation, Ed. 2005. *B Series Multifunction DAQ, 16-Bit, 200 kS/s, 16 Analog Inputs*. Datasheet.

[25] National Instruments Corporation. 2019. *Aeroespacial y Defensa* (2019). Retrieved January 6, 2020 from https://www.ni.com/es-es/innovations/aerospace-defense.html.

[26] National Instruments Corporation. 2019. *Controls Palette*. *Styles of Controls and Indicators* (2019). Retrieved December 27, 2019 from https://zone.ni.com/reference/en-XX/help/371361R-01/glang/controlspalette/.

[27] National Instruments Corporation. 2019. *National Instruments* (2019). Retrieved October 14, 2019 from http://www.ni.com/es-es.html.

[28] National Instruments Corporation. 2019. *PCI-6014 Dispositivo de E/S Multifunción* (2019). Retrieved November 11, 2019 from https://www.ni.com/es-es/support/model.pci-6014.html.

[29] Natural Resources Canada. 2019. *Magnetic components* (2019). Retrieved December 28, 1019 from https://www.geomag.nrcan.gc.ca/mag_fld/comp-en.php.

[30] OpenCircuit. 2019. *MEMSIC 2125 Dual-axis Accelerometer* (2019). Retrieved January 6, 2020 from https://opencircuit.shop/Product/MEMSIC-2125-Dual-axis-Accelerometer.

[31] Parallax_Inc., Ed. 2012. *Memsic 2125 Dual-Axis Accelerometer (#28017)*.

[32] PCB Synotech GmbH, Ed. 2019. *Sensoren für Luft- und Raumfahrt*, Porschestr. 20 – 30 n 41836 Hückelhoven.

[33] Armando Péreza, Rogelio R. Irigoyenb, Gisela Monterob, Conrado Garciab, Jose Rodrigueza, and Marcos Coronadob. 2019. Development and implementation of virtual instrumentation based on LabView applied to compression ignition engines operated with diesel-biodiesel blends. *MethodsX Article,* 6, 2782–2792.

[34] Phidgets Inc. 2016. *Magnetic Sensor* (2016). Retrieved December 11, 2019 from https://www.phidgets.com/?tier=3&catid=5&pcid=3&prodid=78.

[35] Phidgets Inc. 2019. *Absolute Gas Pressure Sensor 20 - 400 kPa* (2019). Retrieved December 11, 2019 from https://www.robotshop.com/en/absolute-gas-pressure-sensor-20-400-kpa.html.

[36] Philips. 2007. *CMPS03 - Compass Module*. *KMZ51 magnetic field sensor* (2007). Retrieved from.

[37] José R. Quezada Peña, Luis H. Neves Rodrigues, Manuel L. da Costa Neto, and Jefferson Oliveira. 2018. ACTIVE METHODOLOGIES IN EDUCATION OF ELECTRONIC INSTRUMENTATION USING VIRTUAL INSTRUMENTATION PLATFORM BASED ON LABVIEW AND ELVIS II. *Global Engineering Education Conference (EDUCON)*, 1696–1705.

[38] Robot Electronics, Ed. 2007. *CMPS03 - Robot Compass Module*.

[39] Amit K. Rohit, Saroj Rangnekar, Anurag Kumar, and Amit Tomar. 2017. Virtual lab based real-time data acquisition, measurement and monitoring platform for solar photovoltaic module. *Resource-Efficient Technologies,* 3, 446–451.

[40] RS Components. 2019. *Pressure Sensor MPX5700DP, 6 pines* (2019). Retrieved January 6, 2020 from https://es.rs-online.com/web/p/circuitos-integrados-de-sensor-de-presion-diferencial/7191119/.

[41] Nan Su, XiaoWei Tu, Yan Tong, XuHui Li, and QingHua Yang. 2019. Design of Data Communication and Monitoring System Based on Aviation ARINC825 Bus. *International Conference on Communication Software and Networks*, 286-290.

[42] Sunfounder. 2018. *Analog Temperature Sensor Module* (2018). Retrieved December 12, 2019 from https://www.robotshop.com/en/analog-temperature-sensor-module.html.

[43] Tal Ronaldinho King. 2019. *File: BASIC Flight instruments Improved.svg* (2019). Retrieved December 4, 2019 from https://commons.wikimedia.org/wiki/File:BASIC_Flight_instruments_Improved.svg.

[44] Texas_Instruments, Ed. 2017. *LM35 Precision Centigrade Temperature Sensors*.

[45] UPC BarcelonaTECH. 2018. *Aerospace Engineering ProjectsM02-S06. DECISIONMAKING*. *Aerospace Engineering Projects Degrees on Aerospace Engineering Technologies and Aerospace Engineering Vehicles ESEIAAT.* Department of Project and Construction Engineering. UPC BarcelonaTECH, Barcelona.

[46] xplore-dna – Didactically Networked Automation. 2019. *Sensorik - Sensorarten* (2019). Retrieved October 16, 2019 from https://www.xplore-dna.net/mod/page/view.php?id=81.

[47] Kunliang Xu. 2015. The Design Concept of a Virtual Experiment Teaching Platform for Digital Logic Based on LabVIEW. *International Journal of Hybrid Information Technology,* 8, 229–236.